GOVERNMENT OF MALAYSIA

NATIONAL WATER RESOURCES STUDY, MALAYSIA

SECTORAL REPORT

VOL. 4

GEOLOGY

[illegible] AGENCY

GOVERNMENT OF MALAYSIA

NATIONAL WATER RESOURCES STUDY, MALAYSIA

SECTORAL REPORT

VOL. 4

GEOLOGY

OCTOBER 1982

JAPAN INTERNATIONAL COOPERATION AGENCY

LIST OF REPORTS

MAIN REPORT

Vol. 1. MASTER ACTION PLAN
Vol. 2. WATER RESOURCES DEVELOPMENT AND USE PLAN

STATE REPORT

Vol. 1. PERLIS/KEDAH/P. PINANG
Vol. 2. PERAK
Vol. 3. SELANGOR
Vol. 4. N. SEMBILAN/MELAKA
Vol. 5. JOHOR
Vol. 6. PAHANG
Vol. 7. TRENGGANU
Vol. 8. KELANTAN
Vol. 9. SABAH
Vol. 10. SARAWAK

SECTORAL REPORT

Vol. 1. SOCIO-ECONOMY
Vol. 2. METEOROLOGY AND HYDROLOGY
Vol. 3. GROUNDWATER RESOURCES
Vol. 4. GEOLOGY
Vol. 5. RIVER CONDITIONS
Vol. 6. WATER QUALITY
Vol. 7. ECOLOGY
Vol. 8. POWER MARKET
Vol. 9. DOMESTIC AND INDUSTRIAL WATER SUPPLY
Vol. 10. AGRICULTURE
Vol. 11. IRRIGATION WATER DEMAND
Vol. 12. INLAND FISHERY
Vol. 13. INLAND NAVIGATION, WATER-RELATED RECREATION
Vol. 14. WATERSHED MANAGEMENT
Vol. 15. WATER RESOURCES ENGINEERING
Vol. 16. WATER SOURCE AND HYDROPOWER DEVELOPMENT PLANNING
Vol. 17. PUBLIC EXPENDITURE AND BENEFICIAL AND ADVERSE EFFECTS
Vol. 18. WATER RESOURCES MANAGEMENT
Vol. 19. WATER LAWS AND INSTITUTIONS

COMPOSITION OF THIS VOLUME

This Volume consists of two parts: Part 1 deals with the subject matters of Peninsular Malaysia and Part 2 is devoted to the States of Sabah and Sarawak.

ABBREVIATIONS

(1) Plan

FMP	:	First Malaysia Plan
SMP	:	Second Malaysia Plan
TMP	:	Third Malaysia Plan
4MP	:	Fourth Malaysia Plan
5MP	:	Fifth Malaysia Plan
6MP	:	Sixth Malaysia Plan
7MP	:	Seventh Malaysia Plan
NEP	:	New Economic Policy
OPP	:	Outline Perspective Plan
RESP	:	Rural Environmental Sanitation Program

(2) Domestic Organization

DID (JPT)	:	Drainage and Irrigation Department
DOA	:	Department of Agriculture
DOE	:	Division of Environment
DOF	:	Department of Forestry
DOFS	:	Department of Fishery
DOM	:	Department of Mines
DOS	:	Department of Statistics
EPU	:	Economic Planning Unit
FAMA	:	Federal Agricultural Marketing Authority
FELCRA	:	Federal Land Consolidation and Rehabilitation Authority
FELDA	:	Federal Land Development Authority
ICU	:	Implementation and Coordination Unit
MARDI	:	Malaysian Agricultural Research and Development Institute
MIDA	:	Malaysian Industrial Development Authority
MLRD	:	Ministry of Land and Regional Development
MMS	:	Malaysian Meteorological Service
MOA	:	Ministry of Agriculture
MOF	:	Ministry of Finance

MOH	:	Ministry of Health
MOPI	:	Ministry of Primary Industries
MRRDB	:	Malaysia Rubber Research and Development Board
NDPC	:	National Development Planning Committee
NEB (LLN)	:	National Electricity Board
PORIM	:	Palm Oil Research Institute of Malaysia
PWD (JKR)	:	Public Works Department
RDA	:	Regional Development Authority
RISDA	:	Rubber Industry Small-holders Development Authority
RRIM	:	Rubber Research Institute of Malaysia
SEB	:	Sabah Electricity Board
SEBC	:	State Economic Development Corporation
S(E)PU	:	State (Economic) Planning Unit
SESCO	:	Sarawak Electricity Supply Corporation
UDA	:	Urban Development Authority

(3) International or Foreign Organization

ADAA	:	Australian Development Assistance Agency
ADB	:	Asian Development Bank
ASCE	:	American Society of Civil Engineers
FAO	:	Food and Agriculture Organization of the United Nations
IBRD	:	International Bank for Reconstruction and Development
ILO	:	International Labour Organization
IMF	:	International Monetary Fund
IRRI	:	International Rice Research Institute
JICA	:	Japan International Cooperation Agency
JSCE	:	Japan Society of Civil Engineers
MOC	:	Ministry of Construction, Japan
OECD	:	Organization for Economic Cooperation and Development
OECF	:	Overseas Economic Cooperation Fund, Japan
UK	:	United Kingdom
UNDP	:	United Nations Development Program

UNSF	:	United Nations Special Fund
US or USA	:	United States of America
US/AID	:	United States Agency for International Development
USBR	:	United States Bureau of Reclamation
WHO	:	World Health Organization
WMO	:	World Meteorological Organization

(4) Others

B	:	Benefit
BOD	:	Biochemical Oxygen Demand
C	:	Cost
CIF	:	Cost, Insurance and Freight
COD	:	Chemical Oxygen Demand
D&I	:	Domestic and Industrial
dia	:	Diameter
EIRR	:	Economic Internal Rate of Return
El.	:	Elevation above mean sea level
Eq.	:	Equation
Fig.	:	Figure
FOB	:	Free on Board
FSL	:	Full Supply Level
GDP	:	Gross Domestic Product
GNP	:	Gross National Product
H	:	Height, or Water Head
HWL	:	Reservoir High Water Level
LWL	:	Reservoir Low Water Level
O&M	:	Operation and Maintenance
Q	:	Discharge
Ref.	:	Reference
SITC	:	Standard International Trade Classification
SS	:	Suspended Solid
V	:	Volume
W	:	Width

ABBREVIATIONS OF MEASUREMENT

<u>Length</u>

mm = millimeter
cm = centimeter
m = meter
km = kilometer
ft = foot
yd = yard

<u>Area</u>

cm^2 = square centimeter
m^2 = square meter
ha = hectare
km^2 = square kilometer

<u>Volume</u>

cm^3 = cubic centimeter
l = lit = liter
kl = kiloliter
m^3 = cubic meter
gal. = gallon

<u>Weight</u>

mg = milligram
g = gram
kg = kilogram
ton = metric ton
lb = pound

<u>Time</u>

s = second
min = minute
h = hour
d = day
y = year

<u>Electrical Measures</u>

V = Volt
A = Ampere
Hz = Hertz (cycle)
W = Watt
kW = Kilowatt
MW = Megawatt
GW = Gigawatt

<u>Other Measures</u>

% = percent
PS = horsepower
° = degree
' = minute
" = second
°C = degree in centigrade
10^3 = thousand
10^6 = million
10^9 = billion (milliard)

<u>Derived Measures</u>

m^3/s = cubic meter per second
cusec = cubic feet per second
mgd = million gallon per day
kWh = kilowatt hour
MWh = Megawatt hour
GWh = Gigawatt hour
kWh/y = kilowatt hour per year
kVA = kilovolt ampere
BTU = British thermal unit
psi = pound per square inch

<u>Money</u>

M$ = Malaysian ringgit
US$ = US dollar
¥ = Japanese Yen

CONVERSION FACTORS

	From Metric System	To Metric System
Length	1 cm = 0.394 inch 1 m = 3.28 ft = 1.094 yd 1 km = 0.621 mile	1 inch = 2.54 cm 1 ft = 30.48 cm 1 yd = 91.44 cm 1 mile = 1.609 km
Area	1 cm^2 = 0.155 sq.in 1 m^2 = 10.76 sq.ft 1 ha = 2.471 acres 1 km^2 = 0.386 sq.mile	1 sq.ft = 0.0929 m^2 1sq.yd = 0.835 m^2 1 acre = 0.4047 ha 1 sq.mile = 2.59 km^2
Volume	1 cm^3 = 0.0610 cu.in 1 lit = 0.220 gal.(imp.) 1 kl = 6.29 barrels 1 m^3 = 35.3 cu.ft 10^6 m^3 = 811 acre-ft	1 cu.ft = 28.32 lit 1 cu.yd = 0.765 m^3 1 gal.(imp.) = 4.55 lit 1 gal.(US) = 3.79 lit 1 acre-ft = 1,233.5 m^2
Weight	1 g = 0.0353 ounce 1 kg = 2.20 lb 1 ton = 0.984 long ton = 1.102 short ton	1 ounce = 28.35 g 1 lb = 0.4536 kg 1 long ton = 1.016 ton 1 short ton = 0.907 ton
Energy	1 kWh = 3,413 BTU	1 BTU = 0.293 Wh
Temperature	°C = (°F - 32)·5/9	°F = 1.8°C + 32
Derived Measures	1 m^3/s = 35.3 cusec 1 kg/cm^2 = 14.2 psi 1 ton/ha = 891 lb/acre 10^6 m^3 = 810.7 acre-ft 1 m^3/s = 19.0 mgd	1 cusec = 0.0283 m^3/s 1 psi = 0.703 kg/cm^2 1 lb/acre = 1.12 kg/ha 1 acre-ft = 1,233.5 m^3 1 mgd = 0.0526 m^3/s
Local Measures	1 lit = 0.220 gantang 1 kg = 1.65 kati 1 ton = 16.5 pikul	1 gantang = 4.55 lit 1 kati = 0.606 kg 1 pikul = 60.6 kg

Exchange Rate
(as average between July and December 1980)

$1 = M$2.22
¥100 = M$1.03

PART 1

PENINSULAR MALAYSIA

TABLE OF CONTENTS

		Page
1.	INTRODUCTION	P-1
2.	GENERAL GEOLOGY	P-2
3.	GEOLOGY OF THE PROJECTS	P-5
	3.1 The Kelantan River Basin	P-5
	3.1.1 General	P-5
	3.1.2 Kelantan barrage	P-6
	3.1.3 Dabong damsite	P-6
	3.1.4 Pergau (downstream) damsite	P-7
	3.1.5 Nenggiri damsites	P-8
	3.1.6 Lebir hydroelectric development project	P-10
	3.1.7 Pergau (upstream) damsite	P-11
	3.2 The Trengganu River Basin	P-12
	3.2.1 General	P-12
	3.2.2 Ulu Trengganu damsites	P-12
	3.2.3 Damsite on the Brang river	P-14
	3.3 The Dungun River Basin	P-14
	3.3.1 General	P-14
	3.3.2 Damsite on the Jengai river	P-15
	3.4 The Kemaman River Basin	P-15
	3.4.1 General	P-15
	3.4.2 Kemaman damsite	P-15
	3.5 The Kuantan River Basin	P-17
	3.5.1 General	P-17
	3.5.2 Damsite on the Kuantan river	P-17
	3.5.3 Kenau damsite	P-18
	3.5.4 Chereh damsite	P-18
	3.6 The Pahang River Basin	P-19
	3.6.1 General	P-19
	3.6.2 Maran damsite	P-19
	3.6.3 Tembeling upper damsite	P-20
	3.6.4 Takai upper damsite	P-21
	3.6.5 Telom and Jelai Kechil damsites	P-22

Page

3.7 The Perlis River Basin P-23
3.7.1 General P-23
3.7.2 Timah Tasoh reservoir P-24
3.8 The Muda River Basin P-25
3.8.1 General P-25
3.8.2 Jenian diversion P-25
3.8.3 Beris damsites P-26
3.9 Other Project Sites P-27
3.9.1 Ahning damsite P-27
3.9.2 Selangor damsite P-28

REFERENCES P-29

LIST OF FIGURES

1. Location Map

1. INTRODUCTION

As a part of the National Water Resources Study, Malaysia, the geological study for Peninsular Malaysia was carried out from 2 November to 27 December, 1980.

Besides the general study of geology in the important river basins, the work was focused upon preliminary assessment from the foundation engineering viewpoint of geological conditions of the sites of dam projects which had so far been proposed and newly contemplated. The study was made on the literatures on regional and local geology of Peninsular Malaysia, published and unpublished, and all the available reports on the project studies. The study also comprised field reconnaissance of more than 25 proposed damsites for hydropower, water supply, irrigation, flood mitigation and multipurpose.

Referred in this report are 23 project sites which are deemed to have high priorities for the time or require careful approach from foundation engineering viewpoint. Those sites are, in alphabetical order, as follows. The mark (x) indicates the site visited for field inspection.

Ahning damsite (Kedah river basin)	
Beris damsites (Muda river basin)	(x)
Brang river damsite (Trengganu river basin)	
Chereh damsite (Kuantan river basin)	
Dabong damsite (Kelantan river basin)	(x)
Jelai Kechil damsite (Pahang river basin)	(x)
Jengai river damsite (Dungun river basin)	
Jenian diversion (Muda river basin)	(x)
Kelantan barrage (Kelantan river basin)	(x)
Kemaman damsites (Kemaman river basin)	(x)
Kenau damsite (Kuantan river basin)	(x)
Kuantan river damsite (Kuantan river basin)	(x)
Lebir damsite (Kelantan river basin)	(x)
Maran damsite (Pahang river basin)	(x)
Nenggiri damsites (Kelantan river basin)	
Pergau (downstream) damsite (Kelantan river basin)	(x)
Pergau (upstream) damsite (Kelantan river basin)	(x)
Selangor damsite (Selangor river basin)	(x)
Takai upper damsite (Pahang river basin)	(x)
Telom damsite (Pahang river basin)	(x)
Tembeling upper damsite (Pahang river basin)	(x)
Timah Tasoh reservoir (Perlis river basin)	(x)
Ulu Trengganu damsite (Trengganu river basin)	

2. GENERAL GEOLOGY

Peninsular Malaysia, as a part of stable cratonic block which covers the Sunda Shelf and Borneo, is composed mainly of Palaeozoic and early Mesozoic sedimentary rocks and intrusive granite masses. The western margin of this block is located in the Indian Ocean along offshore Sumatra Island. Whereas Sumatra is seismically and volcanically active in the recent age, Peninsular Malaysia located back inside the cratonic block is fairly stable in both aspects.

Topography and geology of Peninsular Malaysia are largely governed by the north-northwesterly trend of fold mountain system that is outstandingly represented by the Main Range, the cordillera of the peninsula, which runs longitudinally through the western part of the peninsula. The fold mountain system is traced southward to the Banka and Billiton Islands and northward to eastern Burma and to Himalaya.

The Main Range is presently composed largely of granites, which intruded far later than the upheaval of the prototype of the range. It has been dividing two different sedimentary basins in its western and eastern sides since late Silurian period.

According to the past studies, Peninsular Malaysia has undergone three major orogenic movements; one in the late Silurian to the early Devonian and the others in the late Carboniferous to the early Permian and in the Traissic period. The uprising of the proto Main Range occurred during the orogeny from the late Silurian to the early Devonian, after extensive development of a marine sedimentary basin through the Silurian period, and separated the western sedimentary basin from the eastern counterpart which was later characterized by volcanic activities.

In the next major orogeny in the late Carboniferous to the early Permian, granite intrusion or replacement took place in many parts of Peninsular Malaysia. The orogeny in the early Triassic also brought about an extensive granite intrusions. After widespread volcanic activities in the eastern basin and intensive foldings throughout the Triassic period, the geosynclinal basins rose up completely above sea level to form the land. Accordingly, Peninsular Malaysia lacks marine sediments since the Jurassic period and has only sporadic distributions of inland sediments for Jurassic, Cretaeous and Tertiary. The latest granite intrusions are in the early Tertiary.

The present geological structure with general trend of north-northwest to south-southwest was built up by the Triassic orogenesis. As for the regional fault systems, there exist three major trends. The oldest one is northerly trending normal fault system and the youngest is the sinistral wrench fault system trending north-northeast. The other is a group of relatively long ranged sinistral wrench faults with northwesterly trend, some of which are intensively developed along the Kenaboi river, a tributary of the Pahang river, and in its south in Negeri Sembilan and Selangor.

Intensive foldings are common in the Palaeozoic and Mesozoic formations, with very frequent changes of strike and dip of bedding planes. Regional metamorphism is also widespread but is generally of low grade. Thermal metamorphism is observed rather locally in the form of calcsilicate hornfels and crystalline limestone in the vicinity of granite intrusions.

Cambrian and Ordovician sediments, the oldest in Peninsular Malaysia, are located only in patches in the northwestern part and Lankawi island. The Cambrian beds are predominantly arenaceous, whereas the Ordovician are composed mainly of limestone.

Silurian sediments, which overlies the above formations conformably, are extensively developed in and around the Main Range, torn into many massive blocks by the intrusive granite. They comprise various facies, i.e. carbonaceous and siliceous clastic rocks of every particle size, limestones in the middle and upper zones, local pyroclastic rocks and metamorphic rocks such as phyllite, slate, schist and hornfels.

Devonian formations form belts of exposure on both eastern and western sides of the Main Range, bordering the Silurian and granite province. The rocks are predominantly limestones in central Perak, whereas they are non calcareous conglomerates, grits, mudstones, cherts, phyllites and quartzites in the other areas.

Permo-Carboniferous sediments are largely calcareous. Non calcareous sedimentary rocks are found in the lower Carboniferous beds in the east coast and in northwestern part of Peninsular Malaysia and also in the lower-middle Permian in Kedah. Acidic to intermediate pyroclastic rocks are also widespread in the Permian. Carboniferous beds, together with granites, form the eastern mountain range which develops in the north-northwesterly direction along the western border of Trengganu State, while their distribution in the west coast is in the form of rather isolated patches. Permian system is extensively developed along the eastern foot of the Main Range, the western parts of the eastern mountain range and the southeastern part of the Peninsula.

Triassic to early Jurassic sediments are developed in the northern part of the west coast zone and also covers a large area in the middle zone of the Peninsula between the Main Range and the eastern mountain range. The sediments of upper Permian to lower Triassic are rarely developed. The rocks in the west coastal zone consist of marine arenaceous sediments, that is, predominantly sandstones interpedded with conglomerates, shales, greywackes, etc. The lower Triassic sediments in the middle zone, east of the Main Range, are often composed of limestones and phyroclastic rocks, where they exist. The middle to upper Triassic is characterized by flysh type sediments, consisting of mudstones, shales, sandstones and conglomerates.

Jurassic to early Cretaceous sediments are represented by "Gagau Group" which consists of conglomerates, crossbedded pale coloured sandstones, grey and red mottled siltstones, mudstones and coal beds.

The sediments are continental and show the beds less disturbed than the older formations. They are located in rather small patches in the eastern part of the Peninsula.

Tertiary system, consisting of highly carbonaceous sediments including coal beds, is found in very locally isolated small areas.

Quaternary system includes all of semi-consolidated and unconsolidated deposits consisting of boulders, gravels, sand, silt and clay. Under this category fall river deposits, deltaic deposits, terrace deposits, marine coastal deposits and rhyolitic volcanic ash which has the origin in Lake Toba eruption in Sumatra.

Sedimentary deposits of cassiterite formed in the alluvium are wide-spread sources of tin which is one of the important products of the country. The cassiterite has origin in hydrothermal mineralization in the contact zones of granite and sediments, from where it has been transported by water flow and accumulated into the exploitable concentration in the alluvial sedimentation.

The description in this chapter is based on Refs. 1, 2 and 3.

3. GEOLOGY OF THE PROJECTS

3.1 The Kelantan River Basin

3.1.1 General

The Kelantan river basin covers 13 x 10^3 km^2 of area, or 87% of Kelantan State. The Kelantan river bifurcates into two main tributaries, the Galas river and the Lebir river, upstream of Kuala Kerai, and the Galas river has two major tributaries; the Pergau river and the Nenggiri river. The river system is generally controlled by the north-northwesterly trend and the east-northeasterly trend. The basin is bordered by the Main Range in the west, by the eastern mountain range in the east and by the ridges of Mt. Tahan, Mt. Perlis, Mt. Penumpu and Mt. Gagau in the south.

The eastern border range, El. 300 to 1,200 m, on the right bank of the Lebir river, is composed of granites. The Main Range on the western border, where the Pergau and Nenggiri rivers originate, has 1,000 to 1,500 m of ground height except for several outstanding peaks and is composed of massive granites and Silurian sediments in the western part and of Permian sediments with granite and Taku Schist in the eastern flank. The Permian formations, in which range some proposed dam sites are situated, comprise sediments of various particle sizes, both argillaceous and arenaceous, which are very often regionally metamorphosed into phyllites and slates and further into crystalline schists. Thermal metamorphism due to granite intrusion is often observed in the formation of hornfels. Limestone is extensively developed in the middle reach of the Nenggiri river and to its south.

The middle zone of the basin which includes the southern border ridges is mainly composed of Triassic-Jurassic shales, sandstones, pyroclastic rocks and low grade schists. Patches of Permian metasediments and limestones are also exposed on a line from the upstream Lebir river to Tanah Merah. As against the high ridges in the east and the west, the middle zone is characterized by rather low hills and mild topography, except for the high mountain range in the southern watershed.

In the final 40 km of the river course in the lowest reaches, the Kelantan river flows in the alluvial plane developing around Kota Bharu.

Geological structure is strongly north-south or north-northwesterly trended. The axes of foldings are largely oriented in the above direction, with exceptionally local disturbances due to granite intrusions at places. Major faults are very frequently oriented in the same direction, sometimes intersected by the other group of faults trending northeast to southwest. One of the long-ranged major fault with north-northwesterly trend is located on the right bank of the Lebir river, running parallel to the river course. Minor faults are very commonly found associating with the foldings.

3.1.2 Kelantan barrage

The barrage is contemplated to be low concrete weir for irrigation headwork. The site is located about 2 km upstream of the railway bridge at Tanah Merah.

The Kelantan river flows in a flat plain. The river channel is dissected approximately 10 m deeper than the plain in the surroundings and has 300 to 400 m of width. Both banks of the river channel consist of reddish brown silty loam. According to the unpublished geological map prepared by Geological Survey, Malaysia with scale of 1/63,360, the bedrock on the left side of the river is composed mainly of shale and other argillaceous rocks, whereas the bedrock on the right side is quartzites and other areno-rudaceous rocks. Outcrops of bedrock are rarely found in the barrage site, but a small outcrop of purple shale on the left bank brink confirms the above-mentioned geological map.

The design of the weir structure will largely change depending on the depth of the bedrock under the river deposits. The above-mentioned rock outcrop on the brink of the river suggests that the river deposits are not very thick. In order to confirm this aspect, which will determine the design and the construction cost, geophysical (seismic) exploration across the river and routine core drillings at 50 m intervals on the weir axis are firstly recommended.

Concrete aggregates can be quarried from the granite zone which develops to the east of Machang and more than 8 km to the east of the barrage site.

3.1.3 Dabong damsite

The Dabong damsite on the Galas river is located about 900 m upstream from the confluence of the Jenal river. At the damsite, the Galas river dissects through a north-south trending ridge of more than 300 m of ground height, as against El. 30 m at the riverbed. The river channel is constricted at the damsite to approximately 50 m of width, and the slopes on both banks are almost 1/1 in gradient. Cliff of about 40 m in height above the river is formed on the right bank.

The bedrock is Triassic mica-quartz schist of low grade metamorphism. It is greenish or yellowish pale orange colored and hard to moderately hard. Schistosity strikes generally north-south and dips westward at 55° to 70°. As the direction of the river channel in the site is north-northeasterly, the above schistosity dips toward the river on the right bank. However, the dip of the schistosity being steeper than the right bank slope, it will hardly result in any serious instability of the slope. Overburdens are generally thin, and the bedrocks are exposed widely within 40 meters in height from the riverbed. Weathering is not intensive and develops presumably within a few meters in depth.

Some of joints are nearly parallel to schistosity, and the others show N40°W/50°NW and N80°E/90° in strike and dip. No evidence of significant faulting was observed.

Thickness of the river deposit is unknown, but somes rather small.

The earth or rockfill dam with around 50 m in height has been proposed in the Kelantan River Basin Study (Ref. 5) in 1975. The foundation conditions are deemed sufficiently competent for a fill dam of this height, and almost no essential problems are envisaged in the aspect of foundation engineering.

The said Basin Study in 1975 has proposed the construction material sources within a short distance from the damsite. Borrow pits for impervious earthfill are located in the Jenal valley within 3 km from the damsite and in the left bank about 1 km upstream from the damsite. The materials are yellow to reddish brown stiff clayey silt and residual soil. Quarry is proposed in schist immediately upstream of the damsite. Filter material and fine concrete aggregate are to be taken from the river deposit in the upstream. Coarse concrete aggregates are in the river deposits in the Pergau river within 5 km west and quartz porphiry about 5 km downstream from the damsite.

Approximately 5 km in total length of geophysical (seismic) exploration and 2,000 m of core drilling with water pressure tests will be required in the future to confirm the thicknesses of weathering and river deposit, as well as to examine other geological features, for the damsite and the quarries. Extensive pitting and soil tests are also essential for investigation of earthfill material.

3.1.4 Pergau (downstream) damsite

The site is located near Batu Lembu village on the Pergau river, approximately 8 km east-northeast of Dabong at the confluence of the Pergau to the Galas river. The valley is widely open. The slope on the right bank rises from the river brink at around 1/1.4 in gradient, whereas on the left bank the topography is low and undulating with small hills and winding gullies for about 400 meters in distance from the river channel until arriving at a stable slope.

Bedrocks are exposed sporadically only on the river brinks. Triassic purple and bluish grey shales and coarser grained tuffs compose the bedrock which is moderately hard in general. Bedding show N0°-25°W/35°-55°NE of strike and dip. The outcrops on the river brinks are moderately or slightly weathered. In the up-slope on the right bank, about 30 m higher than the riverbed, the rock is observed intensively weathered almost into residual soil on the cut behind a gauging house. Terrace and low hills on the left bank are thickly covered by reddish brown clayey silt and residual soil.

Considerable width of the valley, ranging about 500 m between the feed of the slopes on both sides and obviously deep and intensive weathering on the slopes render the site less attractive for construction of dam.

Residual soil in thick decomposed zones shall be utilized for impervious earthfill as it is the material abundantly obtainable within a short distance from the damsite. Rock material source is to be prospected in the granite zone 4 km to the west from the damsite. Sand and gravels are obtained from the riverbed deposits.

If a dam should be constructed in this site which involve unfavorable conditions, depth of the fresh rock in the riverbed and on both abutments should be confirmed first of all by means of geophysical (seismic) exploration and core drilling.

3.1.5 Nenggiri damsites

The Nenggiri river was not visited by the writer. The following informations on the damsite geology and based on Ref. 5.

Three damsites were proposed on the Nenggiri river by the Kelantan River Basin Study in 1975. One of them, designated as Damsite No. 6, is located near Batu Baloh, 21 km north-northwest of Gua Musang. Damsite No. 7 is located upstream and about 1.2 km east of the confluence of the Wias river to the Nenggiri. Damsite No. 8 is located about 8 km further upstream No. 7.

In the Damsite No. 6, the bedrocks exposed in the river near the dam centerline and upstream are interbedded meta-sedimentary and meta-pyroclastic rocks, consisting of quartzites, hornfels, schists and altered tuffs. Downstream of the centerline exposed are altered andesitic lavas, apparently interbedded with the sedimentary and tuffaceous rocks. Limestone overlies the meta-sedimentary and meta-pyroclastic rocks conformably, forming high bluffs in the upper parts of the slope on the right bank. According to the said Basin Study, however, the dam structure is likely to be located wholly within the meta-sedimentary-volcanic sequence with possibly some lava occurring on the left abutment. Limestone occurs only at high level (i.e. above about 100 m on the centerline) and the base of this formation will probably be above crest level of the dam. In the reservoir area the base of the limestone formation is rising and appears to lie well above the probable reservoir level.

The other noticeable geological features in Damsite No. 6 are local undulations of bedding planes, their disturbances near the contact with lava, and probably deep weatherings on the left abutment. No evidence of major faulting was seen but faults could be obscured.

The Damsite No. 7 is composed of hard meta-agglomerates. In the vicinity of the site, rocks are exposed extensively along the banks and in the river, forming rapids and a large rock island. The abutments rise steeply on each side of the river. Bedding planes show consistently strikes across the river at N80°E and dips of about 60°SE. A strongly developed set of cross joints, widely spaced and trending N20°W/70°NE, has produced several planer rock faces parallel to the river, particularly on the right bank. Weathering on the abutments is assumed to be of moderate depth. There is no sign of instability on either abutment at high level. No evidence of faulting could be found, but several strong lineations are found in the region. L.H. Chu (Geological Survey, Malaysia) recorded a 3 m wide northeast trending shear zone parallel to the Rengeh river, a tributary of the Wias river. Faults of the similar kind could probably exist.

The Damsite No. 8 is composed of hard calc-silicate hornfels, bedding at N20°E/40°SE and closely jointed in the same direction. Weathering appears deep on the right abutment where no rock is exposed. Instability may develop on the left abutment because of riverward dipping at about 40° and susceptibility of weathered rock to part along the bedding direction. The site has been deemed unfavorable because of wide valley configuration with gentle left bank slope for about 100 m before rising steeply. Limestone bluffs crop out about 5 km upstream.

Apart from the Damsite No. 8, which has been reported as a damsite of rather unfavorable topographic configuration, the Damsites No. 6 and No. 7 are to be investigated in detail for comparison in the future, and then more detailed study of the selected site shall be started. The Report (Ref. 5) says for the site No. 6 that the suitability of the site for dam construction, particularly a high dam, can only be determined after a careful site investigation including drilling the abutment.

A major problem in the Damsite No. 6 is limestone. According to the Report, the limestone formation, although widely jointed, does have occasional major open joints as well as solution cavities which could cause some leakage if submerged. According to the unpublished geological map in scale of 1/63,360 by Geological Survey Malaysia, the limestone is extensively developed on the right side of the Nenggiri river and to the south up to about 7 km upstream from the Damsite No. 6. Though the limestone may not cause much problem in the damsite because it occurs in higher level than reservoir, it should be noticed that the probable reservoir area will extend to the south along a right side tributary, the Pelong river, sharing thin limestone watershed with other river basin. An extensive surface geological mapping will be required to study the condition of the limestone and to confirm its positional relation with the reservoir.

Some stratal disturbances and deep weathering, as reported for the site No. 6, could be overcome technically. However, those foundation conditions should be confirmed by geophysical (seismic) exploration and core drilling with water pressure tests. Required quantity for the first stage for comparison will be at least 3 km in total length for geophysical exploration line and 1,000 m in total depth for core drilling, as for the site No. 6 only.

From topographic map (scale 1/63,360), it seems that in the Damsite No. 7 the height of dam is limited to about 30 m because the ridge on the right bank is low. In this aspect the selected site No. 7 appears inferior to No. 6. However, a higher abutment is obtained about 400 m downstream, though the valley is wider by a quarter than in the site No. 6. Although it is reported that immediately downstream of the selected damsite (No. 7), rock is only occasionally exposed and is generally highly weathered, the downstream alternative may yet deserve the future investigation for comparison, because the topographically allowable height of dam in this alternative can be about 60 m and nearly similar to that in No. 6, under the condition that no saddle dams are constructed.

As for the selected site No. 7, no serious problem of foundation engineering seems to be exist. Probable faults or sheared zones will be treated without difficulties, if their size is 3 m or so, as reported.

For the first stage investigation for comparison in the future, the site No. 7 will require surface geological mapping, 4 km of geophysical exploration and 1,500 m of core drilling with water pressure tests, including study of the said downstream alternative.

Earth material for both Damsites No. 6 and No. 7 and rock material for No. 6 are available in the vicinity of the damsites. Rockfill material for No. 7 is obtainable in the granite zone a few kilometers south of the damsite.

3.1.6 Lebir hydroelectric development project

Feasibility study of the Lebir project (Ref. 6) selected Jeram Panjang damsite on the Lebir river as the most recommendable site. The site is located near Tembeling village, approximately 17 km upstream from Manek Ulai. In this vicinity, the Lebir river forms an incised meander, turning its direction from northerly flow to southerly flow and then again to northerly flow. The right abutment of the damsite is situated on a narrow ridge in the convex side of the meander.

The riverbed at the damsite is 130 wide and at the level of El. 26 m. A rapid is formed on the riverbed. There are river terraces at El. 45 m on both banks. The terrace on the left bank is narrow and composed of silty loam, behind which the slope of decomposed rocks rises at about 1/2.7 of gradient. Another flat is located at El. 100 m on the left bank. On the right bank, the river terrace has approximately 50 m of width and the slope rises at 1/2.2 of gradient from the end of the terrace. The highest continuous contour on the right bank is at El. 100 m with allowance less than 5 m, and this limits the height of dam.

Bedrocks are interbedding tuffs, lappili tuffs, tuff breccias, shales and hornfels, which are hard and occasionally jointed closely. Bedding is monoclinic, with fairly consistent strikes and dips averagely at N40°E/34°SE. No evidence of serious faulting is found, but for minor faults at places.

Fresh or slightly weathered bedrocks are exposed on the riverbed with little covering of river deposits. Outcrops are widespread also on the slopes but are intensively weathered. Thickness of the weathering ranges from 15 to 20 m on the slopes, as revealed by core drillings.

Fill type dam, 69.5 m high, with the high flood water level at El. 90 m has been proposed for this site.

Rock quarry has been proposed for sandstones and cherts in the hills on the left side of the Lebir river. Impervious earthfill material will be taken from decomposed rock zones or residual soil zones. Sand and gravels for filter and concrete are available from the riverbed. If the rocks from the above quarry are not satisfactory in quality or quantity, an alternative quarry would be prospected in the granite zone, 5 km east of the damsite.

Saddle dams are necessitated at two spots; one about 1.1 km northeast and the other 1.4 km northeast of the damsite. Saddle dam No. 1 has been designed to be 67.5 m high and saddle dam No. 2 to be 33.5 m high, both in fill type. Bedrocks for both sites are dacitic tuffs, tuff breccias and tuffaceous sandstones. In the saddle damsite No. 1, sandy overburden has a few meters of thickness and weathering is developed to around 12 m of depth, whereas in the site No. 2 overburden is little and weathering is intensive to approximately 24 m of depth. No significant faults are encountered.

3.1.7 Pergau (upstream) damsite

The so-called Kuala Yong damsite on the Pergau river in its upper reaches is located immediately downstream of the Yong river confluence. The plan comprises pressure tunnel and power station near Lawa village on the downstream Pergau river.

An extensive geological investigation has been performed for this project in 1969 in terms of pre-investment study (Ref. 9). A 70 m high filldam has been proposed.

The river channel is 6 to 15 m wide at the damsite and the slopes on both abutments show 30° to 35° of average inclination with irregular shape due to shallow gullies and local flats.

The site is composed of granite. Intensive weathering is developed on both abutments. Approximately 30 m thick completely weathered granite is reported for the higher level of the slope near the dam crest. Cut-off trench with 9 to 15 m are planned and the use of chemical grouting is proposed for the thick decomposed zones on both wings of the dam.

Most part of the project area is situated in the granite zone. The lower end of the pressure tunnel and power station are in the metasediment zone consisting of quartz-feldspar-mica hornfels, schist and amphibolite.

Comprehensive study has been made for construction materials to be taken from the vicinity of the sites of structures.

3.2 The Trengganu River Basin

3.2.1 General

The Trengganu river basin occupies 4.65×10^3 km^2 of area in the northern east coastal zone. In its western border it shares a north-northwesterly trending watershed range, 300 m to 1,200 m high, with the Kelantan river basin. The northern and southern borders of the basin do not show prominent topographic features but they often run along the low granite rides with north-northwesterly trend.

Geological structure in the basin is generally controlled by the said trend of north-northwest to south-southeast or north to south. Meta-sedimentary rocks of Carboniferous to Triassic which are extensively developed in the basin show a general trend of strikes and folding axes in the above direction. The river system is roughly controlled by the said direction and the other which is right angle to it. Intrusive granites are exposed among the meta-sedimentary rocks, forming also extensive belts of the same trend though not always continuous. Three massive granite zones occur; one composing the western watershed range, the other forming ridges across the middle reaches of the basin and the last interestd by alluvial plain in the lower reaches. Beddings of the meta-sedimentary rocks are often disturbed and show considerable deviations from the said general structural trend in the vicinity of the intrusive granite masses.

Meta-sedimentary facies consists largely of shales, some calcareous and tuffaceous, siliceous sandstones and quartzites which are often interbedded with each other. Grits, conglomerates and other rudaceous rocks also occur locally. Limestone is not well developed in this basin except for isolated intercalations. Andesitic lava flows form strata conformably among the meta-sediments in the upper reaches of the Trengganu river. The shales and sandstones are thermally metamorphosed into calc-silicate hornfels in the surroundings of granites.

Structural faults are local and rather short stretched. A set of east-northeasterly faults is reported in the upper Trengganu and Telemong area. Other groups are in Mt. Padang in the south and near the upstream Kerbat river in the western watershed.

3.2.2 Ulu Trengganu damsites

Trengganu River Basin Study by ADAA in 1976 proposed a couple of damsites in the upper Trengganu river basin. One designated as Damsite No. 4 is located on the Trengganu river about 5.5 km upstream of the confluence of the Tembat river. The other designated as Damsite No. 5 is located on the Tembat river about 6.5 km upstream of the confluence with the Trengganu river. In the plan, water of these two reservoirs are connected through a tunnel and led to power station, 3 km south of the Damsite No. 4. Three saddle dams are necessitated along the ridge between the reservoir and the power station to secure the reservoir flood water level at El. 290 m.

The sites were not visited by the writer.

According to the unpublished geological map in scale of 1/63,360 and the field record of Geological Survey Malaysia, the bedrocks in the area are dark colored coarse grained gritty quartzites, black shales and andesites, all of which form strongly north-south oriented belts. Intruded granite with 1.5 to 4.5 km of east-westerly width is traversed by both the Trengganu river and the Tembat river immediately upstream of their confluence. Hornfels, some with quartz and the others very fine black colored, are formed near the granite mass.

The proposed structures are situated in various rock zones as follows:

Damsite No. 4	:	Shale, very close to granite mass. If this is shifted slightly downstream, it will be in granite.
Damsite No. 5	:	Granite (granodiorite)
Inter-reservoir tunnel	:	Quartzite or sandstone and andesite
Intake tunnel	:	Shale and andesite
Power station	:	Shale
Saddle dams	:	Shale, quartzite and andesite

These rocks are, if fresh or even weathered to some extent, sufficiently strong to support filldams with height of several tens of meters. No serious difficulties are envisaged for tunneling as well, as extraordinarily large fractured zone is not likely to be encountered. A fault along the Tembat river channel through the Damsite No. 5 should be drawn to attention and examined in the future investigation.

Rock material for construction can be quarried from granite, andesite, hornfels and quartzite beds in the close vicinity. Impervious earthfill will be expected from decomposed zone of granite. If the river deposits are not satisfactory for concrete aggregates, it will have to be manufactured from quarry rock.

In the future investigation, surface geological mapping will be performed for every site of structures to clarify their geological situations. Geophysical (seismic) exploration will be required for damsites and tunnel alignments to obtain general pictures of subsurface conditions and to detect obscured weak zones or faults, if any. Core drilling with water pressure tests will confirm the results of the seismic explorations. Pitting and soil tests for earthfill material will be performed for several possible borrow pits.

3.2.3 Damsite on the Brang river

The site is proposed on the upstream Brang river about 4 km upstream of Belukar Bukit village and 3 km downstream of the Lalang river confluence.

Field inspection was not made for this site.

The Brang valley is rather wide open in the site. The bottom of the valley is 200 to 300 m wide and the slopes on both banks show averagely 1/2.5 to 1/4 of gradients, according to topomap. The area appears to be situated in granite zone. According to the unpublished geological map (scale in 1/63,360) of Geological Survey Malaysia, the arenaceous formation, likely consisting of sandstones and quartzites, occurs in the vicinity surrounded by granite mass. These rocks in fresh condition are deemed sufficiently competent for high dam foundation and tunneling. From the topographic flatness, it may be deemed that weathering is deeply developed, say 10 m or more.

Rock material will be quarried from granite zone, and earthfill material is expected to be abundant in decomposed zone of granite or in the flat about 3 km downstream. River deposits will be available for concrete aggregates.

The reservoir area is situated largely in granite and partly in the arenaceous rocks.

In view of probably long dam crest, the future investigation will require estimatedly 10 km of geophysical (seismic) exploration and at least 2,500 m in total of core drilling, for dam, tunnel and power station. Material investigations will have to cover fairly wide area.

3.3 The Dungun River Basin

3.3.1 General

The Dungun river basin has 1.85×10^3 km^2 of catchment area, and is bounded on the west by a north-south trending granite range with 1,000 m or more height. The northern border of the basin is very frequently through high granite ridges. The southern border and the eastern watershed as against the Paka river basin have ground height from El. 400 m to El. 800 m. The basin is narrowed in the outlet to South China Sea through the alluvial plain.

The basin is composed of severely folded Carboniferous meta-sediments intruded by granites and diorites. The meta-sediments comprise carbonaceous slates, phylites, shales and sandstones and are occasionally associated with conglomerates. Granites occur along the western watershed and the eastern watershed between the Dungun and the Paka rivers. Long ranged north-northwesterly to northerly faults are developed through the granites, associated with shorter north-northeasterly fault group.

3.3.2 Damsite on the Jengai river

The proposed damsite on the Jengai river, a right bank tributary of the Dungun river, is located about 6 km upstream of the confluence of the both rivers.

A quaternary flat is formed for approximately 600 m of width in the bottom of the valley and the slope on the left abutment is dissected by closely located gullies into narrow ridges of mild inclination.

According to the 1/63,360 geological map (published), the riverbed and the left abutment area composed of meta-sedimentary rocks and the right abutment is composed of granite. The site is deemed to fit to fill type dam. Approximately 10 m of stripping is to be considered for foundation of impervious core zone from analogy of the occurrences of the same Carboniferous meta-sediments in the eastern area. From the above geological map, it is deemed probable to encounter a fault on the left abutment.

Rock material and concrete aggregates can be taken from granite quarry to be opened on the right bank. Earth material will be obtained from decomposed zones or residual soil.

Because of very long dam axis, at least 3 km of seismic exploration and 1,500 m of core drilling with water pressure tests will be required only for damsite in future investigation.

3.4 The Kemaman River Basin

3.4.1 General

The Kemaman river basin, located in the southern end of Trengganu State, occupies 2.52 x 10^3 km^2 of area. The basin is bordered in the north from the Kerteh, Paka and Dungun basins by granite ridges, and in the west from the Pahang river basin by the 500 to 1,000 m high ridges of granite and meta-sedimentary rocks. In the south, it shares watershed of low hills with the Kuantan river basin.

Most part of the Kemaman river basin is situated in the Carboniferous meta-sedimentary rock zone. Granites are located at places on the watersheds and in the middle reaches of the Kemaman river. The meta-sedimentary rocks mainly consisting of shales, phyllites and sandstones show fairly frequent foldings.

3.4.2 Kemaman damsite

The plan consists of a pair of dams on the Kemaman river and its tributary, the Nipoh river, at about 4.5 km west of Ayer Puteh. The dam on the Kemaman is located 1.5 km upstream of the Nipoh confluence and the dam on the Nipoh is located about 1 km upstream of the same confluence.

In the Kemaman site, the river channel has only 10 m of width and the left bank rises at nearly 1/1.5 of steep gradient, whereas the slope on the right bank is milder. The site is very close to intrusive granite and the bedrock is composed of hard hornfelds, altered from sandstone and shale. Bedding shows N10°-25°W/50°-70°SW of strike and dip, if not always consistent. Overburden and weathering appears rather thin on the left bank, whereas intensive weathering develops more than 5 m on the right bank slope. Thickness of the river deposit is unknown, but probably not thick. No evidence of significant faults was observed. However, a structural fault is recorded to pass through the damsite on the 1/500,000 geological map, and this requires careful research in the future investigation. If the fault is not of serious size, the site appears to be fairly favorable for both filldam and concrete gravity dam.

The Nipoh site has flatter topographic configuration. The river channel is 20 m wide and a low terrace with another 20 m of width is located on the left bank. The slopes on both sides show around 1/2.8 of gradients. No outcrops are found in the damsite. From outcrops up and downstream of the site, the bedrocks appear to be altered sandy shales and fine sandstones which are dark grey or purplish grey colored, hard and mutually interbedded. Joints are moderately spaced and imply no peculiar problem in the aspect of foundation engineering. Bedding shows N50°-60°W/45°-55°SW of strike and dip upstream of the site. About 500 m downstream of the site, quite different strike and dip of N65°E/70°SE is observed immediately downstream of the confluence of the Keladi river, a small tributary. This change of bedding trend may possibly be due to the fault mentioned above. The notably straight line of the Keladi river channel is stretched southwest to meet the part of straight channel of the Kemaman river where a dam is contemplated, and this lineation is very suggestive of a fault line.

Weathering seems thick in the Nipoh site. Up-slope on the left bank, reddish brown residual soil appears 5 m thick or more. Thickness of the river deposits is unknown.

Hornfelds or altered hard sandstones are available for rock material for construction. Residual soil in the decomposed zone can be utilized for earthfill. Good granitic sand and gravels are obtainable from the riverbed around Ayer Puteh.

One of the important subjects of the future investigation is to identify the fault in the Kemaman site. This can be done by careful field geological mapping, geophysical (seismic) explorations with prospecting lines across the valley and core drillings with appropriate inclination. The other matters to be revealed are thickness of the river deposits, thickness of overburden and weathering on abutments and availability of construction material. Approximately 10 km in total length of geophysical (seismic) exploration and 1,500 m of core drilling with packer test will be required for feasibility study. Pitting at more than 20 spots and laboratory soil tests for earthfill material will be also necessary. For planning concrete gravity dam, it is recommendable to excavate test adits of some 50 m in each depth in the damsite for insitu shear tests of bedrock.

3.5 The Kuantan River Basin

3.5.1 General

The Kuantan river basin covers 2.0 x 10^3 km^2 of area, and surrounded by watersheds of which height ranges from El. 300 m to 1,000 m in the inland zone. In the coastal zone, the watersheds are flat low hills.

In the basin extensively developed is Calcareous Series of lower Carboniferous, which consists of mainly shales occasionally associated with siltstones and quartzites, and locally with crystalline limestones. The rocks are altered into slates or phyllites at places.

Arenaceous group of unknown age, consisting of mainly quartzites and subordinate grits, conglomerates and shales, occurs around the Riau river, a tributary in the north of the lower Kuantan river. Tertiary basalt overlies a part of the arenaceous rock and granite in the north of Kuantan.

Tuffs of Pahang Volcanic Series occur in a small local area on the Batu river to the north of the main stream.

Coarse grained granites are exposed along the western and southern watershed and in patches in the northern part of the basin and the vicinity of Kuantan.

3.5.2 Damsite on the Kuantan river

The site is located 1 km downstream of the confluence of the Kulur river to the Kuantan river and about 7 km to west-northwest of Sungai Lembing town.

The river flows east-northeast at the site in a wide valley. Though the slopes on both sides are fairly steep and massive, the river channel has approximately 200 m of width and very mildly rising flood plains, 200 to 250 m wide in each side, are developed on both sides of it.

Outcrop was not found in the damsite and access to the slope was very difficult for dense bushes. Rock fragments in talus deposit suggest that the bedrock is composed of fairly hard sandstones of hornfelds type and slaty shales. From steep inclination of the slopes, overburden and weathering on the slope are deemed not very thick. Probably fresh rock or slightly weathered rock may be reached within 5 m of depth. The riverbed is covered by seemingly thick sand and gravels. Gravels are 1 cm to 15 cm in general size, including also boulders up to 1 m in diameter, and their origin comprises sandstones, slates, hornfelds, quartzites and granites.

Rock fill material can be quarried from altered shales and sandstones on the nearby slopes. Residual soil for earthfill is abundant in the vicinity. The river sand and gravels are good for concrete aggregates.

The widely open valley and probable long dam axis will require a large quantity of core drilling and geophysical exploration in the future investigation. The depth of the river deposits is a questionable matter.

3.5.3 Kenau damsite

The site is located on the Kenau river near Sungai Lembing town and about 500 m downstream from the confluence of the Keboh river to the Kenau.

The river channel is about 50 m wide and the slopes on both banks rise at 1/1.5 to 1/2.0 of gradient. The bedrock in this area is composed of bluish grey to purple colored, hard sandy shales which are metamorphosed due to granite intrusion in the vicinity. Bedding shows some disturbances and strike and dip are not consistent. In the site, however, it shows north-south to northeasterly strikes and eastward dippings. The bedrocks are deemed to provide sufficiently stable foundation for filldams.

The altered hard sandy shales can be well utilized for rockfill and riprap material. Residual soils from decomposed rock zones are available for impervious earthfill. Sand and gravels in the Kuantan riverbed, 5 km north, are good for concrete aggregates and filter zone material.

3.5.4 Chereh damsite

The site is located on the Chereh river, a left bank tributary of the Kuantan river, about 1.2 km downstream of the Balang river confluence.

No field inspection was made for this site.

The Chereh river, with the riverbed level at around El. 30 m, flows south-southeast through the hills higher than El. 150 m. On the topographic map, it appears that the bottom of the valley is about 100 m wide and the slope on the left abutment is rather gentle. According to the 1 inch to a mile geological map of the Pahang part of the Bundi sheet, the site is situated among an extensive area of the lower Carboniferous argillaceous facies which is predominantly composed of shale, dipping at 50° to the east. No prominent faults are reported. Because of probable difficulties in obtaining good rock material in the vicinity, earthfill dam is deemed the most feasible dam type in the site.

3.6 The Pahang River Basin

3.6.1 General

The Pahang river basin covers 29.3 x 10^3 km^2 of area in the central part of Peninsular Malaysia, including the Main Range in the west, the eastern mountain range, the central zone between them and a part of Quaternary plain in the east coast.

Geologically, sedimentary rocks and metamorphic rocks in various grades of all the periods from Silurian to Cretaceous occur in this basin. Massive granite zones of the Main Range from the western watershed with 170 km of length. Massive granite exposures are also located in the eastern watershed and the western parts of the central zone. Triassic sediments cover a large part of the basin, forming a 30 to 90 km wide belt with north-northwesterly trend. Upper Triassic to lower Jurassic sediments which are well exposed in the eastern part of the belt are of continental origin.

The basin is composed of all kinds of agrillaceous and arenaceous rocks, some of which are altered into phyllites, slates and quartzites, and in the vicinity of granite into hornfelds. Rudaceous rocks are occasionally interbedded with those rocks. Altered massive conglomerate with matrix of lithic sandstone is developed in the upper Jelai river area. Pyroclastic rocks are widespread in the northern half of the basin. Limestones occur in places. Andesite lavas are observed intercalating among shales and sandstones in the Tembeling river basin.

Beddings and frequent folding axes are generally oriented north-south to northwest-southeast, with local disturbances around the intrusive granite masses. Long ranged structural faults which are well developed in the eastern part of the basin show the north-northwesterly trends.

3.6.2 Maran damsite

The site is located on the Pahang river approximately 10 km in a crow line from Maran. Contemplated dam axis is on a straight river channel in the direction of west to east immediately downstream of Kerbau Jalang village. Width of the river channel is estimatedly about 160 m. A terrace with 3 m of height from the river water level and 20 to 30 m of width is formed on the right bank. Slopes on both sides rise at 1/1.7 to 1/2 of inclination.

The only outcrop on the left bank is purple tinted pale grey quartz sandstone of medium to coarse grain. At the upstream bend of the river, boulders of white quartz sandstone and pebby conglomerate are found together with white and purple mottles clay which is obviously originated in shale. Downstream to Lubok Paku village, all of the intermittent outcrops on the river banks are coarse sandstones and pebby conglomerates, bedding at N60°W/55°SW. Very probably the foundation rock is composed of interbedding quartz sandstones and purple shales with dominance of sandstones. Thickness of the river deposits is unknown, but they can be thin in places considering those outcrops on the brinks and at the middle of the river. The slopes on both abutments are covered by seemingly thick sandy loam.

Diversion of a great quantity of flood is a problem in construction of dam at this site. If the dam is to be low, the more preferable site may be at about 500 m upstream, where the river channel meanders in a wide open valley forming a 500 m wide flat of silty sand on the left bank. In this alternative site, the present river channel which occupies half the width of the valley bottom may be utilized for river diversion. Bedrocks in this site are deemed to be similar to the original site, but might be deeper under the river deposits.

Fine concrete aggregates can be obtained from river sand deposits. Coarse aggregate source should be prospected in the ridges of hard lithic sandstone and limestone in the west of Paya Baru village, about 10 km west-northwest of the damsite. Earthfill material source will be the widespread sandy loam and clayey silt on the slopes nearby.

Provided that a low dam is planned, the main task of the future investigation will be confirmation of depth of the bedrock, especially under the riverbed and the river terraces, and research and tests of construction material.

3.6.3 Tembeling upper damsite

The Tembeling river in its upper reaches, upstream from Kuala Tahan, forms at many places the narrow gorges constricted by steep slopes which are composed predominantly of quartzites and hard siliceous sandstones. The Pahang River Basin Study by ADAA (1974) proposed a damsite at about 500 m downstream of the Abai river confluence, which is almost similar to so-called Rekan damsite as mentioned below (Ref. 10). In the other hand, Pre-investment Study for Tembeling Hydro-electric Project by Technopromexport (1975) made a series of geological investigations including core drilling for three alternative damsites (Ref. 11). One of the alternatives, which was named Abai damsite, is located about 500 m upstream of the Abai river confluence. The second alternative is the Rekan damsite at about 500 m downstream of the Abai confluence. The other alternative, Lubok-Cherok damsite, is located 1.4 km downstream of the Rekan site, and about 2 km upstream of Kuala Tahan. The contemplated dam height was approximately 60 m.

Each of the three alternative sites is situated in hard quartzite of quartz sandstone zone. Frequent foldings and minor faultings are observed in the Abai site and the Rekan site, but do not appear to have resulted in any serious weakness of rocks in the aspect of foundation engineering. Weathering is intensive up to 10 or 12 m of depth on the slopes in Rekan and Lubok-Chereh, whereas in the Abai site the thickness of intensively weathered zone plus overburden is as much as 20 to 25 m in the upper level of the slope within the height of proposed dam.

Permeability in the rock below the intensively weathered zone shows reasonable ranges in orders of 10^{-4} and 10^{-5} cm/s in each site.

The river channel is 60 m to 80 m wide. In the Rekan site, the slope shows steep inclination of 1/1 on the right abutment and 1/1.6 on the left. The slopes are milder and the valley is open wider in Abai and Lubok-Chereh.

From the above comparison, the Rekan damsite seems most favorable so far as the topographic and geological conditions are concerned. However, the other sites are deemed also feasible from foundation engineering viewpoints.

Every alternative scheme requires approximately 2.5 km long saddle dam on the watershed between the Wa river, a tributary of the Tahan river, and the Siput river, a tributary of the Terengan river. The saddle is situated in the area composed predominantly of shale and sandstone interbeds.

Construction materials are available in the vicinity. Concrete aggregates can be taken from the riverbed deposits. Earthfill materials will be taken from silty clay deposits on the slopes. Hard quartzite and sandstone would provide rock material and concrete aggregates, if necessary.

3.6.4 Takai upper damsite

The site is located on the Tekai river, approximately 17 km east-southeast of the Tekai and Tembeling confluence and about 3 km downstream of the confluence of the Termus river to the Tekai. In the damsite, the Tekai river flows southward through an outstanding ridge of siliceous rocks.

The river channel is approximately 70 m wide and the both banks rise from the river brink with steep slopes of 1/1 to 1/0.85 up to the level 20 m higher than the riverbed. Above this level, the slopes are milder at 1/2.7 to 1/1.7 of gradients.

Bedrocks are white quartzites and quartz sandstones, hard to moderately hard, and are cropped out widely on the river banks and some parts of the riverbed, which is suggestive of rather thin river deposits. Overburden on the slopes is deemed also thin. It appears that weathering deepens up-slope from 20 m of height above the riverbed. Bedding strikes around N30°W, but dip of the beds varies due to folding. An anticlinal axis is located immediately upstream of the damsite, crossing the river diagonally. A synclinal axis seems to exist in the downstream part of the damsite. Minor faults are probable to exist. Joints and cleavages of the rock beds are moderately developed and no peculiar problems are seen.

From the surface inspection, the site appears fairly favorable for construction of filldam and concrete gravity dam. Good sand for concrete is abundant in the downstream riverbed. Coarse aggregate source may be far. This should be searched in as short distance as possible in the future investigation. Rock embankment material would be obtainable from quartzites and sandstones in the vicinity.

3.6.5 Telom and Jelai Kechil damsites

The Jelai Kechil river is a right bank tributary of the Jelai river, of which confluence is located at Kuala Medang, 55 km north of Raub. At about 1.5 km north in a crow line from this confluence, the Telom river from west and the Serau river from east join to start the Jelai river. The Telom river and the Jelai Kechil river in their lowermost 6 km course run east-southeastward nearly in parallel with 3 to 4 km of distance to each other.

The Telom damsite is located about 4.4 km upstream of the confluence of the Telom and the Serau rivers. The Jelai Kechil damsite is located about 3.6 km upstream of the confluence to the Jelai river. In the plan in the Pahang River Basin Study (1974), the reservoirs created by a 60 m high earth and rockfill dam at each site are to be connected with a channel and a 60 MW power station is placed at the foot of the Jelai Kechil dam (Ref. 10).

The both damsites are situated within a stretch of the same outstanding ridge of Silurian conglomerate and quartzites with north-southerly trend. The Silurian meta-sediments comprising quartzite-conglomerates, grits, shales, phyllites, slates and schists are widely developed in the upstream area. Downstream of the above ridge develops a hilly area of lower relief which is composed of calcareous shales of Permo-Carboniferous.

In the Telom damsite, the river channel has about 25 m of width. Slopes on both banks show 1/1 or more inclination, rising directly from the river brinks. Bedrocks, cropping out along the river banks, are highly siliceous and hard quartzites, cherty brown shales and most predominantly conglomerates which contain sub-round quartzite gravels with 2 to 15 cm of diameters in the matrix of hard siliceous lithic sandstone. The overburden appears thin on the both abutments, but several meter thick weathering is deemed to develop. Bedding planes show N40°W/45°-60°NE of strike and dip. Eminent joints are spaced at 20 to 50 cm. River deposits were not visible under the turbid water and their thickness is unknown, but presumably thin. No evidence of major faults was seen. Generally, the site geology seems good for high dam, if the height of dam were not limited by topographic saddles in the southern watershed. Concrete gravity dam would be also feasible technically.

In the Jelai Kechil damsite, the river channel, trending west to east, is 40 m to 50 m wide and the slopes on both sides rise from the brinks at 1/1.4 to 1/1.2 of gradients. Bedrocks crop out intermittently on the river banks and are exposed at a few places above water in the riverbed. The outcrops are composed of quartzites, siliceous lithic sandstones and pebbly conglomerates, which are white to grey colored and hard. The slopes are covered by sandy silts which are probably not very thick. Weathering would be 5 to 10 m thick on the slopes, though not confirmed. Thickness of the river deposits is also unknown but is deemed rather little in view of the outcrops in the riverbed. Strikes and dips show N30°-50°W/60°-80°NE. Joints are spaced averagely at 30 cm and frequently open on the surface. Although the outcrops are not continuous to enable the inspection of entire geological sequence, it is deemed from the massive topographic features of the both banks that essential difficulties in foundation engineering would hardly exist. The foundation rocks in fresh condition are sufficiently hard and solid to support concrete gravity dam as well.

Quarry rocks from the quartzite-conglomerate ridge will be usable for rock material and concrete aggregate. Earthfill material are to be searched in the decomposed rock zone covering the downstream hilly area. River sand in the Jelai riverbed will be utilized for fine concrete aggregates. According to the previous Basin Study, sand and gravel occur along the lower 2 km of the Jelai Kechil, apparently in a series of terraces and infilled meanders, beneath 0.5 to 2.0 m of soil and silty sand (Ref. 10).

In case that the dam crest is at El. 142 m as planned, four saddle dams are necessitated on the eastern watershed of the Satak river, a right bank tributary of the Jelai Kechil. Most of the saddle damsites are possibly situated on the bedrock consisting predominantly of calcareous shales.

The previous Basin Study in 1974 reported the existence of possibly cavernous limestones on outcrops along the Telom river and near an upstream saddle leading to another catchment. Exact location of the saddle is not clear, and it was not visited in the present study inspection. However, this should be one of the major subjects of the future investigation.

The first stage investigation in the future would require estimatedly around 15 km in total length of geophysical (seismic) exploration and more than 2,000 m of core drilling for the main dams and saddle dams, the connecting channel, the power station and material sources, as well as many auger borings and pittings for construction material study.

3.7 The Perlis River Basin

3.7.1 General

The Perlis river basin occupies 730 km^2 of area, that is, nearly 90% of Perlis State except for Langkawi Island. The western watershed of the basin is 150 m to 550 m high limestone ridge of Ordovician Setul

Formation, trending north to south. Northern watershed runs along a chain of high ridges and saddles where the ground height varies from El. 120 m to El. 725 m. The eastern border of the basin is lower than El. 100 m but for a few isolated high hills of limestones. The southern border of the basin is for the most part through the alluvial plain. The basin opens to Melaka Strait in the southwest Kangar.

Other than the Ordovician limestone ridges on the western watershed, the basin is largely divided into two zones, that is, the alluvial plain and the province of limestone and areno-argillaceous sediments of upper Devonian to Triassic. In the latter zone, the limestones are crystalline and dark colored, dense and hard. Solution cavities and caves are often developed in them. The limestone thins eastward and is replaced by siltstones, shales and mudstones. Limestone Monadonocks (isolated hills) remain sporadically on peneplain in the eastern part of the basin.

Tertiary Bukit Arang Coal Bed, consisting of semi-consolidated sediments with thin lignite seams of lacustrine and deltaic origin, is reported to occur in a part of the eastern watershed (Refs. 30, 31, 32, 33 and 34).

3.7.2 Timah Tasoh reservoir

The multipurpose Timah Tasoh reservoir area is located around Tasoh village, approximately 15 km north of Kangar. Around 4.8 km long earth embankment, with height ranging from 2 m to 9 m above the natural ground level, is to be constructed on the west, south and east rim of the reservoir. The southern or the downstream embankment is to be located along the east-west oriented motor road which crosses the Korok river at about 1.4 km south of the confluence of the Timah river and the Tasoh river. The reservoir area is in a flat undulating hill zone, with a northerly trending limestone ridges on the western side. The eastern side of the area rises very mildly up to the watershed at El. 60 to 90 m, and the bedrocks cropping out in the low level are generally composed of purple and grey colored shales and sandstones, though the isolated hills of limestones are scattered there. The shales and sandstones show bedding planes striking N10°-20°E and dipping 45°-60°SE. The reservoir area is extensively covered with calcareous sticky clay and reddish brown lateritic clay. The relation between the limestones and the shale-sandstone beds is obscured under the covering clays. In some trenches and streams in the reservoir area, the coverings are seen to have at least 2 m of thickness, and no bedrocks are cropped out at the bottom of this 2 m.

It seems that the possibility of leakage from the bottom of the reservoir is rather little even if all the area is underlain by limestones, because the clayey deposits covering the area may well be expected to work as impervious blanket effectively against the water pressure less than 1 kg/cm^2, that is created by the reservoir.

The first thing to be done in the future investigation will be to confirm the thickness and permeability of the clayey deposits by drilling and pitting. Core drillings with penetration tests and undisturbed samplings for the embankment foundation will serve greatly also for the above purpose.

In the limestone, well exposed on the foot of the western ridge, many solution cavities and wide open fissures which are resulted from solution along joints and bedding planes are observed. These openings may possibly cause leakages if the reservoir water is in direct contact with the limestone. With this situation in view, the existing plan to construct the western embankment in front of the limestone exposure seems very appropriate (Ref. 12).

3.8 The Muda River Basin

3.8.1 General

The Muda river basin covers 4.3×10^3 km^2 of catchment area developed between the Main Range and Melaka Strait. The basin is bordered in the north and east by the ridges with 500 m to more than 1,000 m of ground height. The warped southern border range descends from around El. 1,000 m in the eastern end gradually to the alluvial plain in the carstal zone. In the west side of the basin, a mountain range with 200 m to 600 m of ground height forms the 60 km long watershed to the Kedah river basin. The watershed to the Merbok river basin, developing to the south of Jeniang, is a chain of lower hills.

The basin geology consists of Silurian and Triassic sediments intruded by granite which occupies fairly large area. The fluviatile and coastal alluvial plain is formed in the narrow outlet of the basin to Melaka Strait.

The Silurian system is a complex of arenaceous rocks largely altered into quartzites, limestones altered into marbles, argillaceous rocks and hornfelds. It is widely exposed in the middle to lower reaches of the main stream and around the Ketil river. The Triassic system comprises shales, sandstones and conglomerates, and widely develops in the northern part of the basin around the upstream Muda river and the southern area around the Karangan river, the Sedim river and the downstream Ketil river.

3.8.2 Jenian diversion

The scheme comprises the 7.5 m high Jeniang diversion barrage, the 10 km long transfer channel, the Noak reservoir, the 18 km long irrigation canal and the pumped storage in the Reman valley with a 33 m high Reman earthfill dam.

The Jenian diversion barrage will be located on the Muda river immediately downstream of Jeneri village. Topography of the site is flat. The river channel is 50 m wide with a low paddy field with about 150 m of width on the left bank. Behind the paddy field develops an extensive terrace approximately 6 m higher than the riverbed. The mild left bank slope is encountered at more than 500 m of distance from the river channel. On the right bank, a mild slope rises behind two stages of terrace at 3 m and 6 m of height and with 80 m of width in total. Rock outcrop is rare in the site. From the outcrops in the vicinity, it is assumed that the site is underlain by interbedded dark grey mudstones, reddish purple shales and quartzites, which generally dip westward. The river deposits may not be very thick but they are very probably underlain by deeply decomposed rocks which are virtually similar to clayey soil. The terraces are covered by silts. Mild slopes are thickly covered by reddish brown clayey silts. Concrete aggregates would be available from the river deposits within a short distance and the granite hills 6 km southeast. Soil and weathered rocks from excavation of the transfer channel will be utilized for embankment material.

The transfer channel passes through flats in the tributary valleys on the right bank of the Muda river. The area is situated in the Silurian shales, mudstones, sandstones and quartzites. It seems probable that the excavation will be largely through intensively weathered soft rocks and residual soils as well as deposits from slope-wash.

The Reman and Noak sites were not visited. The bedrock of the said Silurian sediments are deemed competent enough to support 33 m high earthfill dam. Impervious cut-off trench will have to be excavated to the moderately or slightly weathered rock zone.

3.8.3 Beris damsites

One of the damsites, located on the Muda river about 800 m downstream of Kuala Beris, is the site which was proposed for hydropower generation to be utilized for the Reman pumped storage in the Jenian diversion scheme. The planned structure was a low weir with 8.5 m of height above the riverbed. The river channel is about 40 m wide. A terrace with about 8 m of height and 40 m of width is formed on the right bank, backed by a massive slope rising at 1/2 of inclination. The slope on the left bank is thin and of milder inclination. The bedrock is composed of medium to coarse grained hard sandstones, bedding at N20°E/20°-40°SE. Several outcrops are at the level of the riverbed, and the river deposits appear thin. The terrace is covered by sandy silt. The slopes are covered with seemingly thick mixture of clayey silt and rock fragments. Rock material and concrete aggregates would be obtainable from the sandstone beds and the river deposits in the vicinity. No difficulties are envisaged in foundation engineering of the low weir. Increment of the dam height would be limited at approximately 20 m because of the low watershed on the right bank side.

The other damsite, independent from other schemes, is located on the Beris river, approximately 4 km upstream of Kuala Beris. Field inspection was not made for this site.

In the latter site, the Beris river runs westward with minor meanders, through a northeasterly trending ridge. According to Teoh Lay Hock (1974) of Geological Survey Malaysia (Ref. 13), the gorge in the section of each 400 m up and downstream of the damsite is composed of grey sandstones, quartzites and conglomerates. Bedding shows N20°-70°W of varying strikes and 65°NE to 90° of dips with occasional disturbances. The bedrocks in fresh condition is sufficiently competent for foundation of high dams. Depth of weathering and overburden on the slopes and the riverbed should be confirmed in the future investigation. Hard sandstones and quartzites will provide rock materials for fill dam and concrete aggregates as well. Clayey residual soils and decomposed rocks would be obtainable for impervious earthfill from the slopes in the vicinity.

Careful investigation of the sources for earth material and concrete aggregates will be required in the future, besides the ordinary subsurface studies in the damsite.

3.9 Other Project Sites

3.9.1 Ahning damsite

The site is located on the Ahning river, a tributary in the Kedah river basin, and about 4.3 km east-northeast of Padang Sanai.

No field inspection was made for this site.

The site is situated in a north-southerly trending hill zone. The right abutment appears to be on a massive slope, whereas the left bank slope is divided into rather thin ridges by a few streams.

According to Mohamed Hatta bin Abdul Karim (1979) of Geological Survey Malaysia (Ref. 14), the geological mapping across the southern extension of the same hill zone along the Pedu river, 15 km south of the Ahning valley, encountered a series of interbedding shales, siltstones, sandstones and conglomerates, occasionally associated by cherts. The bedding planes were almost consistently oriented N5°-10°E in strike with varying dips. Small foldings are also recorded.

From the direction of strikes of the above beds, the same kind of bedrocks are expected to occur in the damsite. These rocks can essentially be strong enough for foundation of fill dams with several tens of meter in height. Thickness of weathering and overburden, permeability of rockbeds and construction material sources should be investigated in the future.

3.9.2 Selangor damsite

The site is located on the upstream Selangor river to the east of Kuala Kubu Baharu and about 400 m downstream of the Gerachi river confluence. The river channel is about 30 m wide in the damsite and the slopes rise directly from the river brinks at 1/2 of gradient on the left bank and 1/1.4 on the right bank.

The site is situated in the zone of coarse grained biotite granites. The rocks are deeply weathered and a thick covering of reddish sandy clay which is the product of granite decomposition is observed on the Fraser Hill road on the left bank. Core drilling S3 near the river channel on the left bank, performed in 1966 (Ref. 15), indicates that the bedrock surface is at 3 m of depth and the fairly intensive weathering is seemingly 1.5 m thick. On the other hand, core drilling S2 which was driven from the higher level of the left bank slope, that is, El. 141 m (462.7 ft) or 22 m of height from the riverbed revealed that brown sandy clay was 16 m thick. The underlying granite appears to be intensively weathered for another 5 to 6 m of thickness, considering very low core recoveries of 10% and 45%. This suggests that the interface of moderately or slightly weathered rock zone rises from the riverbed at very mild inclination of 1/7 or less and the intensively weathered zone is badly thickening up-slope. Though the above inclination is deemed possibly to become steeper under the higher part of the slopes, still strikingly deep weathering condition deserves strong attention. Extensive and careful examination of the weathered zone and sandy clay will be required in the aspect of their thicknesses, strength and permeability.

Construction material for fill dam is obtained easily in the vicinity. The reddish sandy clay will be utilized for earthfill material. Hard granite is obtainable within 1 km downstream of the damsite.

REFERENCES

1. GEOLOGICAL MAP OF WEST MALAYSIA (SCALE 1/500,000), 7TH EDITION, 1973, Geological Survey Malaysia

2. MOPI ANNUAL REPORT OF THE GEOLOGICAL SURVEY OF MALAYSIA, 1977, S.K. Chung

3. United Nations Development Program, METALLOGENESIS, HYDROCARBONS AND TECTONIC PATTERNS IN EASTERN ASIA, 1974, Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP) & Inter-governmental Oceanographic Commission, UNESCO (IOC)

4. Geological Survey West Malaysia, DISTRICT MEMOIR 10, GEOLOGY AND MINERAL RESOURCES OF NORTH KELANTAN AND NORTH TRENGGANU, 1967, S. MacDonald

5. Government of Malaysia, THE KELANTAN RIVER BASIN STUDY, GEOLOGICAL INVESTIGATION OF DAM SITES, 1975, ENEX

6. Government of Malaysia, INTERIM REPORT OF FEASIBILITY STUDY OF LEBIR HYDROELECTRIC DEVELOPMENT PROJECT, THE STATE OF KELANTAN, MALAYSIA, 1980, JICA

7. EPU/NEB TRENGGANU RIVER BASIN STUDY, FEASIBILITY REPORT ON MULTI-PURPOSE DAM PROJECT, VOLUME 4 - GEOLOGY, 1976, ADAA

8. EPU WATER RESOURCE DEVELOPMENT IN THE KUANTAN REGION, 1977, Bennie dan Rakan (M)

9. NEB PERGAU HYDROELECTRIC DEVELOPMENT, PRE-INVESTMENT REPORT, VOL. 4, GEOLOGY AND MATERIALS, 1969, ADAA

10. EPU/DID PAHANG RIVER BASIN STUDY, VOLUME 4, FLOOD MITIGATION MEASURES, 1974, ADAA

11. NEB TEMELING HYDROELECTRIC PROJECT, PRE-INVESTMENT STUDY, VOL. 4 GEOLOGY, 1975, V/O "Technopromexport" Hydroproject

12. EPU KEDAH-PERLIS WATER RESOURCES MANAGEMENT STUDY, FINAL REPORT, VOLUME 5 ENGINEERING STUDIES, 1980, Yusoff Ibrahim Sehu/Renardet Engineering

13. Geological Survey Malaysia, FIELD RECORD, SHEET 8, VOL. 2 (Unpublished), 1974, Teoh Lay Hock

14. Geological Survey Malaysia, FIELD RECORD VOL. 1 (Unpublished), 1979, Mohamed Hatta bin Abdul Karim

15. Government of Selangor, Bekalan Air Selangor, INVESTIGATIONS FOR SUITABLE SOURCES OF WATER SUPPLY FOR THE KLANG VALLEY, FINAL REPORT, VOLUME 4, 1980, Binnie dan Rakan (M)

16. Geological Survey Malaysia, FIELD RECORD VOL. 1 (Unpublished), 1979-1980, Yunus Abdul Razak

17. Geological Survey Malaysia, FIELD RECORD, 1950, J.R. Paton

18. GEOLOGICAL MAP (SCALE 1/250,000) NORTH EAST MALAYA, NORTHERN PARTS OF KELANTAN AND TRENGGANU, 1968, Geological Survey West Malaysia

19. GEOLOGICAL MAP (SCALE 1/63,360) TRENGGANU, ULU PAKA SHEET 61, 1975, Geological Survey Malaysia

20. GEOLOGICAL MAP (SCALE 1/63,360) TRENGGANU, GEOLOGICAL SECTIONS ACROSS SHEET 61 (ULU PAKA), 1975, Geological Survey Malaysia

21. GEOLOGICAL MAP (SCALE 1/63,360) KELANTAN, SUNGAI ARING, SHEET 46 AND PART OF SHEET 58, 1978, Geological Survey Malaysia

22. GEOLOGICAL MAP (SCALE 1/63,360) KELANTAN, GEOLOGICAL SECTIONS ACROSS SHEET 46 AND PART OF SHEET 58, 1978, Geological Survey Malaysia

23. GEOLOGICAL MAP OF THE PAHANG PART OF THE BUNDAI SHEET (SCALE 1/63,360), 1951, Geological Survey, Federation of Malaya

24. GEOLOGICAL MAP OF THE SUNGEI LEMBING SHEET, PAHANG (SCALE 1/63,3600, 1951, Geological Survey, Federation of Malaya

25. GEOLOGICAL MAP (SCALE 1/63,360) PAHANG, PARTS OF SHEETS 3-C:11-12, SUNGEI BERA - TASEK CHINI, 1966, Geological Survey Malaysia

26. GEOLOGICAL MAP (SCALE 1/63,360) PAHANG, PARTS OF SHEETS 3-C:15-16, SUNGEI JERAM - TASEK BERA, 1966, Geological Survey West Malaysia

27. GEOLOGICAL MAP (SCALE 1/63,360) PAHANG, BENTA, SHEET 2-N/16 (PART OF NEW SERIES SHEET 67 & 68), 1974, Geological Survey Malaysia

28. GEOLOGICAL MAP (SCALE 1/63,360) PAHANG, KARAK/TEMERLOH, SHEETS 3-C/9 & 3-C/10, 1975, Geological Survey Malaysia

29. GEOLOGICAL MAP OF THE FRASTER'S HILL SHEET SELANGOR, PERAK & PAHANG & THAT PART OF SELANGOR SHOWN ON THE BENTONG SHEET (SCALE 1/63,360), 1949, Geological Survey, Federation of Malaya

30. GEOLOGICAL MAP (SCALE 1/63,360) PERLIS, SHEET 2-E/15, 1967, Geological Survey West Malaysia

31. GEOLOGICAL MAP (SCALE 1/63,360) PERLIS/KEDAH, SHEET 2-E/6, 1967, Geological Survey West Malaysia

32. GEOLOGICAL MAP (SCALE 1/63,360) PERLIS/KEDAH, SHEET 2-E/9, 1967 Geological Survey West Malaysia

33. GEOLOGICAL MAP (SCALE 1/63,360) PERLIS/KEDAH, SHEET 2-E/10, 1967, Geological Survey West Malaysia

34. GEOLOGICAL MAP (SCALE 1/63,360) PERLIS/KEDAH, GEOLOGICAL SECTIONS ACROSS SHEETS 2-E/5, 2-E/6, 2-E/9 & 2-E/10, 1967, Geological Survey West Malaysia

35. GEOLOGICAL MAP (SCALE 1/63,360) KEDAH, SHEETS 2-E/13 & 2-E/14, ALOR STAR & PULAU PAYA, 1972, Geological Survey Malaysia

36. GEOLOGICAL MAP (SCALE 1/63,360) KEDAH, SHEETS 2-I/2 & 2-I/6 (WITH PARTS OF 2-I/3 & 2-I/7) GUNONG JERAI AREA, 1972, Geological Survey Malaysia

37. GEOLOGICAL MAP (SCALE 1/63,360) KEDAH, GEOLOGICAL SECTIONS ACROSS SHEETS 2-I/2 & 2-I/6 (WITH PARTS OF 2-I/3 & 2-I/7), 1972, Geological Survey Malaysia

38. GEOLOGICAL MAP (SCALE 1/63,360) PROVINCE WELLESLEY/SOUTH KEDAH, WEST HALF KULIM AREA (KULIM) SHEET 2-I/10 & PART OF 2-I/11, 1973, Geological Survey Malaysia

39. GEOLOGICAL MAP (SCALE 1/63,360) KEDAH/PERAK, EAST HALF KULIM AREA (KULIM) SHEET 2-I/12 & PART OF 2-I/11, 1973, Geological Survey Malaysia

40. GEOLOGICAL MAP (SCALE 1/63,360) KEDAH PERAK, SHEET 2-I/8 BALING, 1971, Geological Survey Malaysia

41. GEOLOGICAL MAP (SCALE 1/63,360) KEDAH/PERAK, GEOLOGICAL SECTIONS ACROSS SHEET 2-I/8, 1971, Geological Survey Malaysia

42. GEOLOGICAL MAP (SCALE 1/63,360) TRENGGANU & KELANTAN, SHEET 26 (Unpublished), Geological Survey Malaysia

43. GEOLOGICAL MAP (SCALE 1/63,360) SHEET 37 ULU TELEMONG (Unpublished), Geological Survey Malaysia

44. GEOLOGICAL MAP (SCALE 1/63,360) SHEET 45 GUA MUSANG (Unpublished), Geological Survey Malaysia

45. GEOLOGICAL MAP (SCALE 1/63,360) SHEET 49 BUKIT BEST (Unpublished), Geological Survey Malaysia

46. GEOLOGICAL MAP (SCALE 1/63,360) SHEET 59 KUALA SAT (Unpublished), Geological Survey Malaysia

47. GEOLOGICAL MAP (SCALE 1/63,360) SHEET 67 KUALA MEDANG (Unpublished), Geological Survey Malaysia

48. GEOLOGICAL MAP (SCALE 1/63,360) SHEET 70 SUNGAI TEKAI (Unpublished), Geological Survey Malaysia

FIGURES

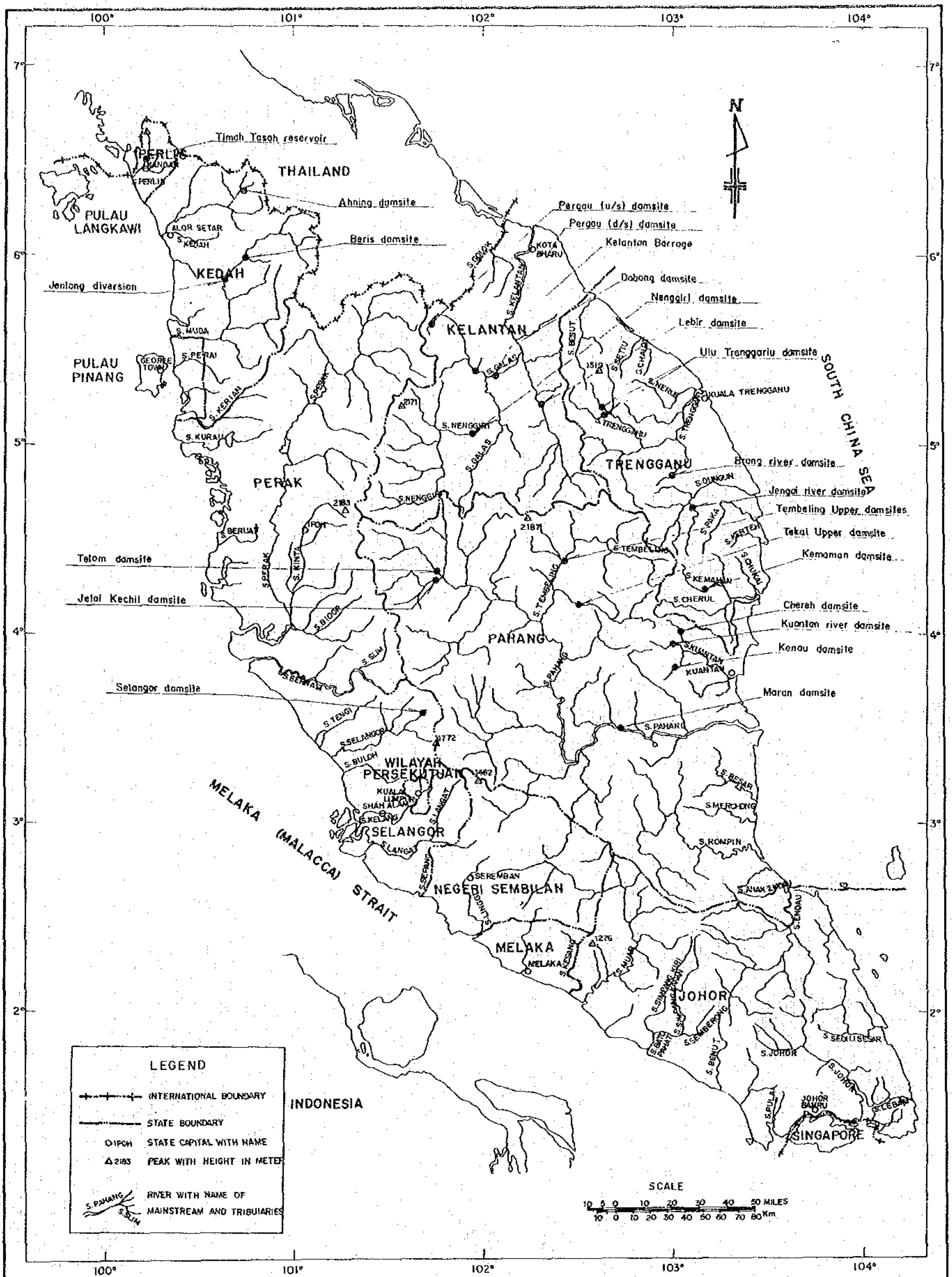

Fig. 1 Location Map

GOVERNMENT OF MALAYSIA

NATIONAL WATER RESOURCES STUDY MALAYSIA

JAPAN INTERNATIONAL COOPERATION AGENCY

PART 2

SABAH AND SARAWAK

TABLE OF CONTENTS

		Page
1.	INTRODUCTION	S-1
2.	GENERAL GEOLOGY	S-3
3.	GEOLOGY OF THE PROJECTS IN SABAH	S-7
	3.1 The Crocker Range	S-7
	3.1.1 General	S-7
	3.1.2 Kadamaian damsite	S-9
	3.1.3 Tuaran damsites	S-10
	3.1.4 Moyog damsites	S-13
	3.1.5 Papar damsites	S-14
	3.1.6 Sook damsite	S-16
	3.1.7 Padas damsite	S-16
	3.2 The Pensiangan River Basin	S-17
	3.2.1 General	S-17
	3.2.2 Damsites	S-18
	3.3 The Kinabatangan River Basin	S-19
	3.3.1 General	S-19
	3.3.2 Damsites	S-19
	3.4 Tawau Area	S-21
	3.4.1 General	S-21
	3.4.2 Tawau damsite	S-21
	3.4.3 Kinabutan damsite	S-22
	3.4.4 Balung damsites	S-23
	3.4.5 Merotai damsites	S-24
4.	GEOLOGY OF THE PROJECTS IN SARAWAK	S-26
	4.1 Kuching Area	S-26
	4.1.1 General	S-26
	4.1.2 Tebia damsite	S-26
	4.1.3 Semadang damsite	S-27
	4.1.4 Bengoh damsite	S-28
	4.1.5 Kedup damsite	S-29
	4.1.6 Batang Kayan damsite	S-30

Page

4.2 The Kemana River Basin S-31
4.2.1 General S-31
4.2.2 Damsites S-31

4.3 The Rajang River Basin S-31
4.3.1 General S-31
4.3.2 Damsites S-32

REFERENCES S-35

LIST OF FIGURES

1. Structural Zones of Borneo

2. Location of Dam Site in Sabah

3. Location of Dam Site in Sarawak

1. INTRODUCTION

As a part of the National Water Resources Study, Malaysia, Phase III, the geological study of Sabah and Sarawak was carried out from 30 September to 28 November, 1981.

Besides the study of general geological situations of Sabah and Sarawak, the work was focused upon preliminary assessment of the foundation engineering conditions of geology in the sites of potential dam projects which had so far been proposed and newly contemplated. The study comprises the review of literatures and data on regional and local geology, published and unpublished, and the previous project reports. Field reconnaissance of the project area was also performed for 28 days.

Referred in this report are more than thirty project sites as listed below in alphabetical order. The numbers in the parentheses show the sub-chapters of reference to the sites. The mark (x) indicates the site visited by land for field inspection, and the mark (xx) shows the site inspected from an air-born helicopter.

- Sabah

Balat damsite		(3.3.2)	
Balung damsite	No. 1	(3.4.4)	(x)
	No. 2	(3.4.4)	(x)
Deramakot damsite		(3.3.2)	
Kadamaian damsite		(3.1.2)	(x)
Kinabutan damsite		(3.4.3)	(x)
Kuamut damsite		(3.3.2)	
Merotai damsite	No. 1	(3.4.5)	(x)
	No. 2	(3.4.5)	(x)
Milian damsite		(3.3.2)	
Moyog damsite	No. 1	(3.1.4)	(x)
	No. 2	(3.1.4)	(x)
Padas damsite		(3.1.7)	
Papar damsite	No. 1	(3.1.5)	(x)
Pensiangan damsite		(3.2.2)	
Sapulut damsite		(3.2.2)	
Sibungo damsite		(3.2.2)	
Sook damsite		(3.1.6)	(x)
Sumatalun damsite		(3.2.2)	
Tagul damsite		(3.2.2)	
Tawau damsite		(3.4.2)	(x)
Telekosang damsite		(3.1.7)	
Tuaran damsite	No. 1	(3.1.3)	(x)
	No. 2	(3.1.3)	(x)
	No. 3	(3.1.3)	(x)

- Sarawak

Balu 027	(4.3.2)	(xx)
Balu 037	(4.3.2)	(xx)
Balu 112	(4.3.2)	
Batang Kayan damsite	(4.1.6)	(x)
Bela 010	(4.3.2)	
Bela 030	(4.3.2)	
Bele 014	(4.3.2)	
Bengoh damsite	(4.1.4)	(x)
Kedup damsite	(4.1.5)	(x)
Lina 013	(4.3.2)	
Muru 008	(4.3.2)	(xx)
Muru 040	(4.3.2)	
Pandan damsite	(4.2.2)	(xx)
Pesu damsite	(4.2.2)	(xx)
Raja 284	(4.3.2)	(xx)
Raja 285	(4.3.2)	(xx)
Semadang damsite	(4.1.3)	(x)
Tebia damsite	(4.1.2)	(x)
Tubau damsite	(4.2.2)	(xx)

2. GENERAL GEOLOGY

Borneo has its base in a stabilized cratonic block which extends to the Sunda Shelf and Peninsular Malaysia and is composed of the Palaeozoic to Mesozoic meta-sedimentary rocks associated with intrusive and extrusive rocks ranging from acidic to ultra-basic. In the late Cretaceous, so-called Northwest Borneo Geosyncline started to develop along the northern margin of the craton, forming thick Tertiary sediments to cover the older formations. Tectonic movements, represented by strong foldings, developed from south to north along the geosyncline during the period from the Upper Creteciam to Upper Eocene. Following the above development, the geosynclinal basin changed into shallow sea, where formed were younger neritic sediments of the late Tertiary covering the geosynclinal flysch deposits.

The above geological units are exposed in the belts of concentric arc which is open to north, in orderly sequence of the older to the younger from south to north. According to Haile (Refs. 1 and 2), the West Borneo Basement, composed of the Palaeozoic and early Mesozoic metamorphic and intrusive rocks, and the Kuching Zone, where thick Tertiary deltaic sediments cover Palaeozoic-Mesozoic formations, occupy a large area of Indonesian Kalimantan. The Sibu Zone, the northern belt adjacent to the Kuching Zone, is the core of the Northwest Borneo Geosyncline, consisting of the Upper Cretaceous to Eocene flysch with ophiolites which are intensely folded. To the north of the Sibu Zone develops the Miri Zone which is composed of areno-argillaceous and calcareous sediments formed in shallow sea environment during the period of Miocene to Pliocene.

Sabah and Sarawak in the northern part of Borneo are situated in their most part on the belt of the Northwest Borneo Geosyncline, or the Sibu and Miri Zones. The rocks older than the Upper Cretaceous are cropped out only in the Division of Tawau in East Sabah and in the Kuching area west from the Lupar river in West Sarawak. The East Sabah area was a geosynclinal backdeep or a kind of a branch basin from the Northwest Borneo Geosyncline, where thick flysch type deposits were accumulated on the pre-Triassic Crystalline Basement. Accordingly, the Sabah and Sarawak regions consist of three characteristic geological provinces, that is, Eastern Sabah sedimentary basin, Northwest Borneo Geosyncline which covers central Sarawak to West Sabah, and West Sarawak on the craton.

Geological structures are strongly controlled by the trend of the geosyncline and the arcuate zones of the craton in the areas of Northwest Borneo Geosyncline and West Sarawak. Foldings are intensive, sometimes with very steeply dipping bedding planes. Axes of the foldings and strikes of the bedding planes are generally parallel to the above trend, that is, east-westerly in the west and central Sarawak and gradually turning northward in the eastern region until it reaches north-northeasterly orientation in western Sabah. Major structural faults are not very frequent. Well developed ones of them are found running northerly to north-northeasterly through Witte and Trusmadi ranges in Sabah. In Eastern Sabah, east of the above faults, Strikes of the bedding planes show northwesterly or easterly trends in general.

The oldest rocks exposed in the Sabah and Sarawak area are the outcrops of the Kerait Shist consisting of Pre Upper Carboniferous quartz-mica schists which are located in the southern vicinity of Kuching in form of small patches among the Quaternary coastal deposits. They are succeeded by intensely folded limestones, shales and cherts of the Terbat Formation of Upper Carboniferous to Lower Permian. The Sadong Formation overlying the Terbat Formation with unconformity is composed of Upper Triassic shales, sandstones and conglomerates, and is closely located with the contemporaneous products of the Serian volcanic activity in the south of Kuching and the upper reaches of the Sadong river.

In Jurassic period, a geosynclinal sediments of the Serabang Formation which comprises pelitic hornfels, slates, greywackes, cherts and marbles with interbedded basic lavas and tuffites were formed in the vicinity of Sematan near the western end of Sarawak. From the late Jurassic to Cretaceous, a thick limestone and the overlying sandstones, shales, siltstones, grits, cherts, conglomerates of the Bau and the Pedawan Formations were deposited in a subsiding basin in the south of Kuching. Generally, in the period through Jurassic and Cretaceous, the sedimentation took place only in the western part of the Sadong river and its tributary the Krang river. This may suggest that the eastern part from the Sadong-Krang line had been emerged above sea level in this period.

The other old formation which had been formed before the Northwest Borneo Geosyncline developed is located in the hinter-land of Darvel bay in East Sabah. The Crystalline Basement is composed of gneisses, schists, amphibolites and quartzites with metamorphosed gabbroes, dolerites and volcanic rocks, locally intruded by diorite-granite rocks associated with hornfels. The radiometrically estimated minimum age is reported to be Lower Triassic. Its exposure forms patches of approximately 300 km^2 of area in the northwest of Darvel bay and the upper reaches of the Segama valley. The patches of outcrop are bordered by faults, some of which are obscured under the younger sediments.

Development of Northwest Borneo Geosyncline started in the late Cretaceous. Initial sediments of shales, siltstones, sandstones, greywackes and conglomerates, with cherts and ophiolitic rocks are developed north of the Lupar river. The contemporaneous Chert-Spilite Formation comprising sandstones, red shales, radiolarian cherts, pillow lavas and limestones were formed covering the Crystalline Basement in the area west of Darvel bay in Eastern Sabah.

Main part of the Northwest Borneo Geosyncline is represented by the provinces of the Rajang Group in central Sarawak and the Crocker Formation and others in Sabah. The Rajang Group is extensively developed in and around the Rajang river basin in more than 170-km wide belt, composed of hard sandstones, shales, siltstones and slates with some conglomerates and limestones of Upper Cretaceous to Eocene. The Crocker Formation and other geosynclinal flysch formations in Sabah, which were formed during Palaeocene through Miocene, are well developed in Crocker range, Witte range and Trusmadi range in western Sabah and extend to Eastern Sabah. The members of the sediments are hard sandstones, shales, some siltstones and conglomerates with local limestones and tuffs.

Orogenic movement which resulted strong folding of the flysch sediments started in Lake Cretecions Eocene in central Sarawak, and developed gradually northward through the rest period of Neogene. Shallow marine deposition developed from Eocene in central Sarawak, whereas it occurred in Mio-Pliocene period in the northern part of the geosynclinal province. In Eastern Sabah also the marine shelf or deltaic sedimentation started in Miocene. These shallow marine sediments continued through Neogene in Eastern Sabah basin and in the northernmost belt of the Northwest Borneo Geosyncline or the Miri Zone, while the basins continued to subside. In these inner neritic areno-argillaceous deposits the present oil fields are located.

In Dent peninsula, Eastern Sabah, the sedimentaiton of inner meritic deposits continued to Pleistocene.

Alluvial plains are extensively developed in the lower reaches of major rivers, such as the Kinabatangan, Padas, Baram, Rajan, Sadong and Lupar rivers.

Igneous rocks occur extensively in Eastern Sabah and West Sarawak and sporadically in the Geosyncline area. Triassic or older intrusive rocks are seen in the form of metamorphosed basic rocks in Crystalline Basement in Eastern Sabah, together with Triassic diorite-granite rocks. In West Sarawak, an eminent volcanic activity in Triassic is represented by outcrops of the Serian Volcanic Formation which is predominantly basaltic. Also, intrusive granites and diorites in the early Mesozoic are exposed at many places in the west of the Lupar river. During Jurassic and Cretaceous period, basic volcanic rocks accompanied with the geosynclinal deposition of the Serabang, Sibuyau, Bau Formation and granitic intrusions occurred in the Lundu area in the extreme west of West Sarawak.

Ophiolitic volcanic activity took place during the geosynclinal sedimentaiton after the late Cretaceous through Miocene. Basic and ultra-basic intrusions occurred in Sabah. Orogenic movement from Eocene to Miocene was followed by post-orogenic igneous activities which produced the acidic to intermediate rocks, e.g. the dacitic lava and tuffs in Hose Mountains in central Sarawak.

Existing Mamut copper mine is located on the southeastern slope of Mt. Kinabalu in Sabah. The other copper mineralizations are located in its vicinity and in the province of basic rock intrusions around the Labuk river. It is reported that the Mamut copper mine deposit is of low-grade prophyry-type associated with Tertiary adamellite-granodiorite intrusions. Gold and antimony are mined in Bau, West Sarawak. Coal occurs in the deltaic deposits of the Silantek and Plateau Sandstone Formation in West Sarawak and in the Miocene strata of central and north Sarawak. The oil fields off-shore the northwest coast is extracting crude oil from oil traps of fault and anticline complex in the Mio-Pliocene inner neritic sediments.

The above descriptions are based on Refs. 1 to 3.

3. GEOLOGY OF THE PROJECTS IN SABAH

3.1 The Crocker Range

3.1.1 General

The Crocker range is a chain of mountains with 1,000 to 2,000 m of ground height which develops in the northwestern part of Sabah, elongated in the direction from northeast to southwest, nearly parallel with the coast line. It reaches to Mt. Kinabalu in the north, and its southern extension runs southerly through the region of the upper Padas and Tomani rivers.

In the east side, adjacent and parallel to the Crocker range stretches a chain of Witti and Trusmadi ranges, and between the pair of these mountain chains a wide valley of the upper Padas and Pegalan rivers are developed.

The Crocker range, including its coastal foothills, is largely composed of Oligocene to Lower Miocene sandstones and shales of the Crocker Formation, which also prevail in the Witti range and western parts of the Trusmadi range. The sandstones are light grey, yellowish grey and bluish grey coloured, fine to medium grained and hard. The bluish grey ones are very hard in particular. The shales are bluish grey and chocolate brown coloured, moderately hard and sometimes flaky.

The sandstones and shales form alternation, with thickness of each layer ranging from a few centimeter to more than 5 m. Thick and massive sandstone layers often occur. In some zones, on the contrary, the alternation is regular repetition of 5 to 10 cm thick layers of sandstone and shale. Bedding planes, generally well developed but rather obscure in massive sandstones, trend mostly north-south to north-northeasterly, but for northwesterly strike in the vicinity of Tambunan and Keningau. Dips of the bedding planes are steeply eastward in many cases but sometimes to the west. Mild warps of bedding planes are prevalent.

The Crocker range is source of many rivers which flow to the northwestern coast of Sabah, such as the Kadamaian, Tuaran, Moyong, Papar, Kimanis, Puas, Membakut and Padas rivers. All of them except for the Padas are the rivers of medium to minor scale with catchment area less than 1.5×10^3 km^2, which arise on the northwestern slope of the range. The Padas river, with 9.18×10^3 km^2 of catchment area, has its numerous heads in the Witti-Trusmadi ranges and on the southeastern slope of the Crocker range, and breaking through the latter in Tenom to Beaufort section pours into South China Sea.

From foundation engineering point of view, the sandstones and shales of the Crocker Formation are sufficiently competent in strength and watertight or, at least, easily treatable for watertightness to be foundation of high fill type dams. If a site of thick sandstone or predominantly sandstone is selected, a concrete gravity dam will also be technically feasible. A couple of strong joint sets, which are nearly perpendicular to the bedding plane, are commonly developed at 30 cm to 1 m intervals and minor strike faults and slickensides are found occasionally. However, they are not any serious defects in particular which may cause such problems as to jeopardize a feasibility of dam. It seems that ordinary groutings can be sufficiently effective for foundation treatments.

The shales of the Crocker Formation characteristically have a tendency to deteriorate in the surface exposed to air into an irregular mosaic of fragments by rapidly developing fine cracks due to loss of moisture and shrinkage. The deterioration reaches usually only to about 30 cm of depth. This can be prevented by covering the excavated surface of shale immediately after the exposure.

Thickness of weathering appears to range from 5 to 10 m, and more than 10 m in places, particularly on thin ridges and flat terrain. The top 1 to 3 m zones are decomposed into reddish brown residual soil. The weathered rock zone should be excavated to reach fresh rock interface for the foundations of concrete gravity dams and fill dam's impervious core zone. Hence, the 5 to 15 m deep excavation will have to be envisaged for dam abutments. Weathering seems thinner in the level of river beds. Fresh or only slightly weathered rocks are often cropped out on the river brinks.

River channels in the Crocker range are filled by sand and gravel deposits, of which thickness is unknown. Gravels are generally of hard sandstones, and those with more than 10 cm up to boulders in size occupy a big proportion in the middle to upper reaches of rivers. The sand appears to be biased to fine.

The other geological unit composing the Crocker range is the Tembrong Formation of Upper Oligocene to Lower Miocene which consists of shales and siltstones. This facies occurs in the Padas valley between Tenom and Beaufort, interfingering with the Crocker Formation, and is well developed to the south of the Padas river. Where it is interfingered with the Crocker Formation, it is often difficult to distinguish from the shales of the Crocker Formation. This can be treated, in the aspect of foundation engineering, in a similar way to the Crocker Formation shales.

Construction materials for dams and other structures in the Crocker range are commonly available within a reasonable distance. Hard sandstones can be good rock material for rockfill dams. Reddish brown residual soil, which is proximity of silty clay, with underlying weathered rocks is the sole abundant source for earth material. Concrete aggregates are to be obtained from the river deposits. To collect a large quantity of smaller gravels for concrete aggregate, some long haul distance from the downstream reaches or locations of suitable gravel deposits may be necessitated. Otherwise, the concrete aggregates can be manufactured from the very hard bluish grey sandstones.

It is deemed in general that high fill dams or concrete gravity dams can be technically feasible within a reasonable cost in the Crocker range, as well as the Witti range and a part of the Trusmadi range, or in the province of the Crocker Formation, if the damsites are situated at locations of geomorphologically massive and thick abutments.

The examples follow.

3.1.2 Kadamaian damsite

The Kadamaian river arises on the southern slope of Mt. Kinabalu, and turning around its southwestern foothill runs northward to pour into South China Sea near Kota Belud. Distance of its run, disregarding meanders, is approximately 50 km.

The Kadamaian damsite is contemplated at Tumbokon village, 6 km northwest of Mt. Sadok Sadok in the territory of Kinabalu National Park and 23 km south of Kota Belud.

The riverbed, approximately at El. 230 m, is 30 m wide and flows northward forming incised meander. A tributary Kilambun river joins from the right side. Immediately upstream of the confluence, the right abutment is situated on the slope of the foothill of Mt. Sadok Sadok, which rises almost directly from the river brink up to about 60 meter's height and then turns to mild inclination. On the left bank develops a 30 m wide river terrace, a few meter high, and a steep slope of 1/1.2 in gradient rises behind it.

The bedrock is predominantly sandstones of the Crocker Formation, intercalated by shales. The sandstones are sufficiently hard and can be stable foundation of high dam. Bedding planes trend N40°W/50°SW in strike and dip. Outstanding joints show N80°E/40° to 60°NW and N40°W/30°NE. A minor fault with slickensides, trending N80°E/60°NW, is observed on the left bank, which does not comprise any serious fractures. As against the above geostructural trends, the dam axis will have orientation in E-W or ESE-WNW. The bedding planes in the sandstones are spaced at 70 cm to 3 m of intervals. Joints being not seriously frequent, the bedrock is generally massive.

Weathering is intensive and deep in the vicinity. On the left abutment, however, the bed rock is only slightly weathered for 6 m of thickness below thin top soil which is 1 m at thickest. The right bank appears to be weathered thicker.

The originally contemplated damsite is located about 400 m downstream, that is, immediately downstream of the confluence of the Kilambun river to the Kadamaian. In this site, a wide terrace a little higher than the river bed is formed on the right bank and the slope behind it is low and thin for about 500 m of length along the dam axis. Weathering on this thin abutment is possibly very thick. The dam crest will inevitably longer there. Foundation excavation and the dam volume will be larger, though this site has a merit of adding the catchment area of the Kilambun river.

Hard bluish grey sandstones are good sources for rock material for rockfill dam. Residual soil plus thick weathered rocks in the downstream area are usable for earth material. Concrete aggregates are obtainable from the river deposits downstream.

Questionable matters for this damsite are thicknesses of weathering on the right abutment and gravel deposits in the riverbed, which have to be examined by geophysical (seismic) exploration and core drillings. Appropriate quarry site should be located after detailed geological mapping and core drilling.

3.1.3 Tuaran damsites

The Tuaran river originates on the northwestern slope on the Crocker range in the vicinity of Mt. Alab (El. 2,086 m), 40 km southeast of Tuaran, and flows down northwestward through Tamparuli and Tuaran until it reaches to the river mouth at 7 km northwest of Tuaran.

Eight alternative damsites are contemplated on the Tuaran river and its major tributary Mulau river. Three sites downstream from the Mulau confluence were inspected.

(1) The Tuaran damsite No. 1

The Tuaran damsite No. 1 is located about 1 km upstream of Tamparuli. The river channel at approximately El. 15 m is westnorthwesterly oriented with around 60 m of width. The slope on the right bank rises with around 1/1.7 of gradient from the river brink, whereas the slope on the left bank rises at 1/1.2 behind a river terrace, a few meter higher than the riverbed and about 100 m wide. In spite of small gullies on the slopes, the both abutments are sufficiently massive and stable.

The bedrock is alternation of yellowish grey medium to fine grained hard sandstones and bluish grey flaky shales. The sandstones are hard enough to be a concrete gravity dam foundation. The shales are inferior in strength and likely to develop hair cracks on the surface quickly after exposure to atmosphere. Bedding planes, well developed at less than 60 cm of intervals, show consistent strikes and dips around N45°E/55°SE. Joints are also well developed trending in N30°E/45°NW, N30°W/80°NE and N60°W/90°. The bedding planes cross the river at right angle or obtuse angle and dip upstream. Though some of the fissures are slightly open, they can be treated by grouting of ordinary procedure without much difficulties.

Weathering appears rather deep. At least 10 m of excavation will be required on the both abutments to expose reliable foundation rocks for concrete gravity dam and impervious core zone of fill dam. Thickness of the river gravel deposits is unknown. Any particular difficulties are not foreseen for construction of a fill type dam.

It seems that the hard sandstone beds are the sole source of the rockfill material. Quarry site should be located in thick sandstone beds or in an area where the sandstone is predominant, to minimize the proportion of soft shales mixed in the quarry rocks. Earth material will be obtained from the residual soil or decomposed rock zones plus weathered rock zones near the site.

Gravels of hard sandstone are obtainable from the riverbed and terrace deposits. The river sand appears to be fine. Check of the grain size distribution will be required in the future investigation. If the river sand is not satisfactory in quality, the production of fine aggregate for concrete from quarry rock may have to be considered.

Probably, troubles with this damsite are its too close distance to the town of Tamparuli and a considerable amount of villages and cultivated lands to be submerged under the reservoir. This situation will be more relaxed as damsite is shifted more upstream.

(2) The Tuaran damsite No. 2

Located upstream in Kiulu village, 8 km south-southeast of the damsite No. 1 as the crow flies, the Tuaran damsite No. 2 is at approximate ground height of El. 60 m in the riverbed. The riverbed is about 30 m wide and oriented northwesterly at the damsite. The left bank is a convex side of meander, and the slope of the abutment with around 1/1.7 of gradient is about 150 m apart from the river channel. River terrace, a few meters high, is developed between the river channel and the slope. On the right bank a steep slope at approximately 1/1.2 rises from the river brink up to 10 m of height and is followed by a milder slope in the higher parts. Slightly weathered sandstone outcrops are continuous at the foot of the right bank slope.

The bedrock is composed of yellowish grey sandstones intercalated with bluish grey and chocolate brown shale layers of the Crocker Formation. The bedding planes strike N30°E to N40°E and dip at 50° southeastward, or upstream. Trends of joints are N5°W/80°SW, N15°E/60° to 70°SE, N50°W/40°NE, etc. The bedding planes and the joints are rather frequent, spaced at 20 cm to 1 m intervals.

If predominance of the hard sandstone beds, as seen on the outcrops, is confirmed by core drillings, a concrete gravity dam or at least a combined concrete gravity and fill dam will be feasible, and this will enable the river diversion without tunnels, taking advantage of the low terrace on the left bank. In the other hand, considering the possible long dam crest and large dam volume as against the height of dam due to wide open valley, a rockfill dam plus diversion tunnels may be more economical. It depends on scale of the dam and the flood discharge, as well as the geological condition of the diversion tunnel alignment.

Conditions for the construction material is similar to those in the damsite No. 1.

Careful investigation will be necessary about thickness of weathering. So far as seen on some outcrops, weathering appears to be 7 to 10 m thick. However, as the abutment ridges on both banks are considerably thin, there can be the parts of deeper weatherings in the higher levels of the slopes. This should be checked by seismic exploration and core drillings at 50 m intervals.

(3) The Tuaran damsite No. 3

The Tuaran damsite No. 3 is located further upstream at Pukak village, 5 km southeast of the damsite No. 2 and immediately downstream from the confluence of the Mulan river. The river channel, trending west-northwesterly, is at about El. 120 m and approximately 30 m wide. The slope on the right bank is massive, while that on the left bank projecting close to the river is relatively thin and mildly inclined along the dam axis. Still some 100 m wide river terrace lies between the left bank slope and the river channel.

The bed rock is sandstone and shale alternation. Weathering appears to be deeper than 10 m on the slopes. Reddish silty clay containing rock fragments covers the slopes at places. Bedding planes trend N25°E to N35°E in strike, almost right angle to the river, and 55° to 60°SE in dip. No serious problems are envisaged for construction of rockfill dam.

Conditions for the construction materials are similar to those in the other alternative sites.

(4) Comparison of the alternatives

From foundation engineering point of view, the damsite No. 1 is most preferable because of its massive abutments and smaller distance between the slopes on both banks. Naturally the catchment area is largest. The demerit is that the assets to be submerged are also largest.

Between the damsites No. 2 and No. 3, there seem to be no great differences in the geological and topographic conditions. Compensation for the submerged assets is minimized in the damsite No. 3, while the loss of catchment area is 259 km^2 as against No. 1 which would take 710.5 km^2 of total catchment area.

The other contemplated damsites in the upstream Tuaran and the Mulau rivers are deemed to be in the similar geological conditions of the Crocker Formation. The preference will depend largely on the aspects other than geology.

3.1.4 Moyog damsites

The Moyog river has its head on the western slope of Mt. Alab, and flows westward, intensively meandering, to pour into South China Sea in the south of Kota Kinabalu. The distance on a straight line from the head to the sea is approximately 25 km.

(1) The Moyog damsite No. 1

This site is located at 1 km southeast of Madjiang village, 11 km east-southeast from Kota Kinabalu. The river is about 30 m wide and at around El. 15 m of ground height. The river channel shows north-northwesterly flow at the damsite. The abutments are on massive and stable slopes, inclining at about 1/1 on the right bank and 1/1.7 or steeper on the left bank. The topographic feature at large is a deep gorge with profile of V-shape.

The bedrock is the yellowish grey coloured, fine to medium grained, hard sandstones, intercalated by thin shales. Well developed bedding planes strike north-northeast and dip at 60 degrees eastward. Joints show N60°E/70°NW, E-W/55°N, etc. The intervals of the bedding planes vary from several centimeters, often in the shale layers, to 3 m, in parts of massive sandstones. Joints are spaced at 30 cm to 1 m.

Depth of weathering appears to be various according to the localities. While reaching more than 10 m in some thin ridges, it is within several meters in general.

Both a concrete gravity dam and a fill type dam are applicable to this damsite. No big problems are envisaged from foundation engineering viewpoint.

The fresh sandstones are sufficiently hard to be utilized for rock-fill material. Residual soil, mixed with the underlying weathered rock, for earth material can be taken in flat areas and thin ridges around the tributaries. The river deposits in the vicinity of the damsite contain in high proportion big cobbles and boulders. Concrete aggregates may better be looked for in the downstream area. Otherwise, concrete aggregates can be produced from quarried bluish grey sandstones which are dense and hard. For the yellowish grey sandstones, though hard, there is fear of inferiority especially in abrasion. Concrete aggregate tests are essential.

(2) The Moyog damsite No. 2

The damsite No. 2 is located at 800 m west of the confluence of the Kibunut river and about 7 km upstream from the damsite No. 1.

The river bed, 25 m wide, is at about El. 105 m according to the 1/50,000 topographic map. The river channel is oriented to northwest. An approximately 100 m wide terrace which is 3 to 6 m higher than the riverbed is developed on the right bank, and a slope with about 1/1.2

of gradient rises behind it up to 270 m of height. On the left bank, a slope of 1/1.2 is formed at the riverside up to 10 m of height and then a mild slope follows for about 200 m of length until it changes to the massive and steep slope of the left bank ridge.

The foundation rocks are composed of hard sandstones with intercalations of bluish grey and chocolate brown shales of the Crocker Formation. Mildly folding bedding planes show N25°E/30°SE to N10°E/60°SE of strike and dip. The observed joints trend N35°W/65°NE, N50°E/65°NW, N50°W/40°SW, etc.

Weathering seems to be within several meters' depth. Fresh or only slightly weathered sandstones are exposed continuously on the left brink of the river and partly under the terrace on the right bank. Outcrops of slightly weathered sandstones are seen also on the road-cut on the slope of the right bank, about 40 m higher than the river.

Conditions for the construction material are similar to those in the damsite No. 1.

The damsite is deemed suitable for both a concrete gravity dam and a fill type dam. The valley is wider here than in the downstream alternative, which will result in approximately 50% longer dam crest. Submergence of the existing paved road from Kota Kinabalu to Tambunan, hence its relocation, is inevitable for both alternatives.

3.1.5 Papar damsites

The Papar river originates on the western slope of Mt. Alab, 35 km east-southeast of Kota Kinabalu, and flows down westward to Himpangno at about 30 km west from Mt. Alab. Then it turns southwestward and reaches to Mandalipau, 15 km as the crow flies from Himpangno. In the final 15 km section from Mandalipau to the sea, it takes northwesterly course at large, with intensive meander, through the Quaternary plain around the town of Papar.

The Papar damsite No. 1 is located near the river bend immediately downstream of Dompon village. The river bed, at about El. 110 m, has around 100 m of width. Massive ridges are located close to the river on both sides, enabling to layout a dam axis in the north-northwesterly direction. The slope on the left bank is as mild as 1/5 in gradient, whereas that on the right bank shows about 1/2.5. The slopes are steeper up to around 1/1.7 nearby the river channel. A flood terrace with approximately 6 m of height from the riverbed and 60 m of width is formed on the right bank.

The bedrock is the alternation of sandstones and shales of the Crocker Formation, with unit layers ranging from a few centimeters to almost 10 m in thickness. Hard sandstones crop out on the river brink of the left bank. Strike of the bedding planes shows north-south to north-northeasterly directions. Dips are 60° or more to west.

The westward dip is not common in the Crocker Formation, and the prevalent dips of strata in the upstream and downstream area are easterly. It seems that this local abnormally of dipping direction is due to inversion of strata in a part of mildly warped folding. However, some faulting might be involved. Though no serious fractures or disturbances are observed in the outcrops, an overall examination of the damsite by detailed geological mapping and geophysical (seismic) exploration is recommended.

Weathering appears to be within several meters in the lower parts of the slopes, but could be thicker up-slope.

In view of rather high proportion of shale beds, a rockfill dam is recommendable.

Fresh sandstones can be utilized for rock material. Reddish brown residual soil and weathered rocks for earth material are abundant in the vicinity. Gravels and sand deposit along the Papar river seems sufficient in quantity for concrete aggregates. The quality should be tested in the future investigation.

The above damsite was proposed by SMEC (Ref. 39) in 1963, as a part of a project to divert water from the Papar river to the vicinity of Labak village at 3 km east of Kinarut by a 4 km long tunnel through the Crocker range, for the purpose of power generation and water supply. The outlet of the tunnel would be located on the upper Kinarut river, at about El. 60 m and in the area of the sandstone shale alternation striking NNE and dipping 50° to 60°E. All the structures are situated in the Crocker Formation.

The other damsite on the Papar river proposed by SMEC is located about 2 km upstream of the above damsite, and at 400 m downstream of the confluence of the Himpangno river. The valley is wide open in this site and the left abutment is on a narrow and low hill. This can be the site for low intake weir.

Two alternative sites, one at 1 km west of the Terian river confluence and the other immediately downstream of the Bonobukan river confluence, were not visited for inspection. According to the 1/50,000 topographic map, their abutments are on the slopes of massive ridges. The foundations are obviously the Crocker Formation rocks. Technical feasibility is probably positive in the way similar to the other sites in the Crocker Formation.

The slopes appears stable in the Papar river basin in general. Possible collapses under the surging of reservoir would be of only minor scale without any substantial harm to the safety of the structures.

3.1.6 Sook damsite

The Sook river arises in the southern part of Trusmadi range at about 30 km east-northeast of Keningau. It runs around the southern end of the range, turning its course from southwestward to westward and then to northward through 80 km of distance, and joins to the Pegalan river in the south of Keningau. The Pegaran river is a tributary of the Padas river.

The Sook damsite is located about 8 km south-southwest of Keningau. The riverbed is at El. 249 m, with about 25 m of width. A 61-m high earthfill dam has been planned at this site.

The surroundings are undulating hilly area of low relief. The slopes on both banks are mildly inclined at 1/2 to 1/3.

The bedrock is the sandstone and shale alternation of the Crocker Formation, which crops out at places on the river banks. Bedding planes show north-northwesterly trends with around 40 degrees of easterly dips. The bedrock is sufficiently competent for foundation of an earth dam. Leakage through fissures would be treatable by means of cement grouting.

The bedrocks appear to be weathered within 5 to 10 m of depth from the ground surface on the slopes. About one third of the weathered zone is deteriorated into reddish brown clayey residual soil.

Sufficient quantity of earth material is available in the residual soil and weathered rock zones in the vicinity. Concrete aggregates will be obtainable in the downstream river bed and in the Pegalan river.

In the first stage of the future investigation, the depth of fresh rock interface should be confirmed by core drilling with water pressure tests at 50 m intervals on the dam axis. Also, the quality of earth material and concrete aggregates need to be examined in laboratory tests.

The slope in the reservoir area is generally stable except that some minor slip-down of surface soil is observed. Little possibility is seen for land slidings of hazardous scale.

3.1.7 Padas damsite

The Padas river, originating on the northern slope of the border ridge to Indonesia at 100 km south from Tenom, runs northward through Kuala Tomani to Tenom. Turning to the west at Tenom, it traverses the Crocker range up to Beaufort and pours into South China Sea.

The Padas damsite No. 1 is located about 7 km southwest of Tomani, and the Padas damsite No. 2 is at 7 km west-southwest of Melutut village. The site inspections were not made because of swelling of the Padas river.